The 2nd Workshop on Synergy between Carbon Management and Biodiversity Conservation in Tropical Rain Forests

30 Nov – 1 Dec 2005

Forest Research Centre, Forestry Department, Sandakan, Sabah, Malaysia

Workshop Proceedings

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Proceedings of the International Workshop

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Cover photo: Canopy of the forest harvested by reduced-impact logging in Deramakot, Sabah, Malaysia (photo by Hisashi Matsubayashi)

The 2nd Workshop on "Synergy between Carbon Management and Biodiversity Conservation in Tropical Rain Forests" was held in Forest Research Centre, Forestry Department, Sandakan, Sabah, Malaysia on 30 November and 1 December 2005 to discuss issues pertinent to the reconciliation of carbon sequestration and biodiversity conservation in production forests.

The workshop was organized by Sabah Forestry Department and DIWPA (DIVERSITAS in Western Pacific and Asia).

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DIWPA is an international network for promoting cooperative studies and information exchange on biodiversity, in the region of Western Pacific and Asia, under a close cooperation with its mother program, Diversitas, organized by IUBS, SCOPE and UNESCO

http://diwpa.ecology.kyoto-u.ac.jp/index.htm

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FOREWORD

Among the ecosystem services we expect from forest ecosystems, carbon sequestration and biodiversity conservation have increasingly received the attention of the people in the world. However, the forest with high rate of carbon sequestration is not always the one with high species diversity. We tend to plant fast growing, and sometimes exotic trees in monoculture to obtain extremely fast growing volume of timber. Such a forest usually does not foster the indigenous biodiversity.

It is a challenging trial to introduce CDM to involve one of the ecosystem services into the economic account of forests. However, still there are many other ecosystem services that have not recognized very importantly. Biodiversity is one of the most difficult one to evaluate economically. However, biodiversity or biological interactions in ecosystems drive the ecosystem; if some parts of them were lost, some important functions and services of ecosystems would be lost. In such a sense, biodiversity is closely associated with sustainability of ecosystems and its utilization. It is natural that biodiversity is included as important criteria and indicators of sustainable forest management.

It is a great step towards such a goal that Dr. Ying Fah Lee, Dr. Yaw Chyang Chung and Dr. Kanehiro Kitayama are publishing the proceedings of the 2nd international workshop on 'Synergy between Carbon Management and Biodiversity Conservation in Tropical Rain Forests' held at Sepilok, Sabah on 30 November, 2005. I am very pleased that DIWPA (Diversitas in Western Pacific and Asia) and my project in RIHN (Research Institute for Humanity and Nature) helped the workshop together with APN (Asia Pacific Network for Global Change Research) and Sabah Forest Department. I hope the workshop could enlarge its activity to find effective solution for the conflict between carbon and biodiversity.

Tohru Nakashizuka
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Chair, Diversitas in Western Pacific and Asia

PREFACE

Climate change is of global concern as it affects virtually everyone on this planet. With the general agreement that climate change is likely to occur as a result of human activities, countries are increasingly concerned about the likely adverse impacts of climate change. The role of forest in climate change remains to be one of the most contentious issues in negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The forests are a major reservoir of carbon, containing some 80% of all the carbon stored in land vegetation, and about 40% of the carbon residing in soils. The UNFCCC called for the stabilization of "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous (human) interference with the climate system". The Kyoto Protocol, a significant legally binding treaty created under the UNFCCC for greenhouse gas emission reduction, came into force in February, 2005. The Protocol incorporates the vital role of forests and wetlands in its mechanisms to reduce greenhouse gases. Forestry activities can influence the amount of greenhouse gases in the atmosphere because forests can act both as a sink (absorbing emissions) and as a source of emissions when trees are felled. When a tree or forest is increasing in size, it absorbs carbon as part of the process of building up its biomass - a growing forest is a sink. Thus, sustainable forest management is the way forward in ensuring that more carbon is absorbed than being released. Being a Party in the Protocol, Malaysia is now committed to the full implementation of the Clean Development Mechanism (CDM). It is the only one of the three mechanisms for climate mitigation under the Protocol that allows the participation of the developing countries including Malaysia. Concurrently, the Convention on Biological Diversity (CBD) emphasizes the conservation and sustainable use of forests and wetlands that harbour biological diversity. The rich biological diversity of the forest will be threatened by rapid climate change. Guidelines need to be developed without sacrificing these mutually exclusive requirements. Hence, more studies should be conducted to understand carbon management and biodiversity conservation.

The publication of the Proceedings of the 2nd International Workshop on 'Synergy between Carbon Management and Biodiversity Conservation in Tropical Rain Forests' held at Sepilok, Sabah, on 30 November, 2005, is timely. The information contained in this volume demonstrates the application of the concept of synergy between carbon management and biodiversity conservation in production forests, which has been suggested by international participants in the workshop. It is also meant to disseminate the results of the on-going research conducted by researchers from the Sabah Forestry Department and also Japanese researchers. Most of the research is carried out at the Deramakot Forest Reserve, a Commercial Forest Reserve that has been certified as a well-managed forest by SGS Malaysia based on the principles and criteria of the Forest Stewardship Council (FSC). Undoubtedly, such collaborative research work would further strengthen Deramakot as a model for demonstrating the synergy between carbon management and biodiversity conservation in productive forests at the international level.

I wish to thank the organizers of the workshop, the editors of this volume, and also Asia Pacific Network for Global Change Research and the Research Institute for Humanity & Nature, Japan, who have kindly funded this workshop.

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The Clean Development Mechanism (CDM): constraints and opportunities for the Sabah forestry sector

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Abstract Brief accounts of the recent development in the international negotiations of the climatic treaty as well as the stand and efforts on climate change issue done at the federal and state level with regard to the forestry sector are given. Ineligibility of funding for forestry carbon projects under the current rules of the Clean Development Mechanism (CDM) is seen as a major constraint for the forestry sector to play an influential role in combating climate change. Non–CDM funding may provide a short–term solution to the already constricted financial situations in the forestry sector. Capacity building of the Sabah Forestry Department is seen as a viable opportunity to be taken up by this seminar.

Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), there has been an unprecedented warming trend during the 20th century (UNFCCC 1994). The current average global surface temperature of 15°C is nearly 0.6°C higher than it was 100 years ago and scientists estimate that it could rise another 1.4°C to 5.8°C by the end of this century (IPCC 2000). The ten (10) warmest years have all occurred in the past fifteen years, the 1990's being the hottest decade on record. The six main greenhouse gases (GHGs) that are linked to global warming are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

The increased rate of emission of these gases have manipulated the 'greenhouse effect' to warm the earth to a degree that will have devastating ecological, social and economical consequences. Regional and global assessments have indicated the profound impact that climate change will have on water supplies, agricultural productivity, biodiversity and human health.

As a consequence of the worldwide concern over global warming, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 at the Earth Summit in Rio de Janerio. Currently, 186 countries are Parties to the Convention (UNFCCC 2005). The UNFCCC aimed at stabilizing the concentration of greenhouse gases (GHGs) in the atmosphere. Subsequently in 1997, the convention endorsed the Kyoto Protocol, an agreement requiring the industrialized (Annex I) nations to reduce their GHGs emissions to an agreeable level by 2012[1]. The Kyoto Protocol entered into force on 16 February 2005 following Russia's ratification that has met the requirement of having at least 55 Parties to the UNFCCC, incorporating Annex I Parties which accounted in total for at least 55% of the total carbon dioxide emissions for 1990.

To ease the financial burden of "cleaning up" of GHGs emissions in the Annex I countries, the Protocol provided for a flexible mechanism known as the Clean Development Mechanism (CDM) for these parties to implement their carbon sequestration projects in the developing nations (Non – Annex I). As a developing country, Malaysia is currently not subjected to any commitments towards reducing greenhouse emission under the protocol[2].

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[1] A brief description of the Protocol is given in Appendix 1.
[2] The national leadership however had set the year 2020 as a target for the achievement of a developed nation status. Depending on an assessment of the status of carbon emission at that time, Malaysia would have to be

This paper describes briefly both the recent development of the negotiations at the various Conferences of Parties (COP) and the latest stand on the CDM and climate mitigation efforts both at the national and state levels.

Malaysia's commitment on global warming

Malaysia signed the UNFCCC on June the 9th in 1993 and ratified it on the 17th of July 1994. Since then as a member of the G77 and China group, Malaysia has always contributed actively to the rounds of negotiations at the UNFCCC. To reflect the implementation of its commitments, a National Climate Committee (NCC) was established in 1995 under the auspices of the then Ministry of Science, Technology and Environment. Funding by the Global Environment Facilities (GEF) was provided in 1997 to strengthen and assess Malaysia's GHG baseline data, and to develop institutional expertise and adaptation strategies for GHG emissions[3].

Efforts on the National Communication

Under the stewardship of the National Steering Committee on Climate Change (NSCCC), Malaysia submitted its Initial National Communication (INC) to the UNFCCC in 2000, which is required by Article 12 of the Convention. The INC was an output of the UNDP/GEF Project "Enhancement of Technical Capacity to Develop National Response Strategies to Climate Change".

The INC, prepared in accordance with the guidelines adopted in Decision 10/CP.2, was a first step in the country's implementation of the UNFCCC (MNRE (CEMD)/DANIDA 2005). The preparation of INC involved scientists, experts and individuals from various government agencies, universities, research organizations, non-governmental organizations and private entities. Background documents pertaining to climate change scenarios, inventories of GHG, assessment of impacts of climate change, public awareness and education and abatement measures were prepared.

As a party to the UNFCCC, Malaysia will continue to communicate to the Convention on its national GHG inventory and information on activities envisaged to implement the Convention. As such, Malaysia has recently begun the preparation of Second National Communication (NC2), not merely to fulfill its commitment to UNFCCC, but also to enable the country to identify national priorities and needs in order to facilitate decision-making by the policy makers. The Ministry of Natural Resources and Environment (NRE) has initiated several activities, through the support of DANIDA, to contribute to the preparation of its NC2[4].

The Sabah Forestry Department (SFD), under the 9th Malaysia Plan (RMK 9), has submitted a proposal for carbon sequestration and other climatic mitigation studies for Federal government funding. Initial development so far indicated a possibility of getting the fund approved. Further refinement on the proposal may still be necessary to align its objective to the major development thrusts of the Malaysian forestry sector under the RMK 9.

The Clean Development Mechanism (CDM)

The CDM was established under Article 12 of the Kyoto Protocol, for climate change mitigation projects between Annex I countries and non-Annex I countries. The CDM was established for two (2) purposes, namely, to assist the non-Annex 1 Parties in achieving sustainable development thereby

prepared for an emission target to be kept if she is found to be a net carbon emitter. Under the Initial National Communication, Malaysian forests are found to be a net carbon sink.

[3] Based on 1994 data, Malaysia's greenhouse gas emissions totaled the equivalent of 181 million tonnes of carbon dioxide. Net emissions after accounting for sinks totaled the equivalent of 112 million tonnes. The land use change and forestry sector involves both the emission and sink of GHGs. Emissions of CO_2 occurs mainly through the forest and grassland conversion, which totaled about 7,636 Gg in 1994. The changes in forest and other woody biomass stock result in a net CO_2 sink of about 68,717 Gg. The on-site burning of forest releases some 0.132 Gg of CH_4 and 0.001 Gg of N_2O in 1994. (FRIM, 2003).

[4] Apart from the finalisation of technical reports, altogether seven (7) activities had been identified under the NC2 work plan. These are analysis of the National Circumstances, GHG inventory, facilitation of adaptation and mitigation measures to climate change, analysis of relevant information in the achievement of the objective of the Convention and identifying constraints, gaps, related financial, technical and capacity needs.

contributing to the UNFCCC's objectives, and to assist the Annex I Parties in achieving their GHG emission reduction targets through implementation of carbon-offset projects in the non-Annex I countries. All CDM project investments must also be independently certified. This latter requirement gives rise to the term "certified emissions reductions" (CERs), which describes the output of CDM projects. The CERs generated by such project activities will be used by the investing Annex I Party to help meet their emissions targets under the Kyoto Protocol.

The Annex I Parties are expected to contribute financing, technology transfer, and other support for these projects in the developing countries. Project implementation, however, would have to adhere to a number of defined rules and procedures set by the COP and to be approved by the CDM Executive Board. Both Rahim (2005) and Shamsuddin *et al.* (2005) described further the other features of the CDM and the role of forestry in mitigating climate change with regard to the carbon management activities.

For forestry carbon offset projects the output would be termed as temporary and long-term CERs (tCERs and lCERs) as the CO_2 sequestrated could be released into the atmosphere in the case of forest fire and diebacks. Parties may offset their emissions by increasing the amount of greenhouse gases removed from the atmosphere by so-called carbon "sinks" or reducing emissions in the land use, land-use change and forestry (LULUCF) sector. However, due to restrictions under some of the Protocol's Articles, only certain activities in this sector qualify for CDM funding.

Government views on the CDM

Malaysia became a signatory to the Kyoto Protocol on 12th March 1999 and announced the country's ratification of the Protocol during the "Second Earth Summit" on 4th September 2002 in South Africa. Being a party to the Protocol, Malaysia is committed to the full implementation of the CDM in an equitable manner and sees it as a vehicle that can create opportunities for investments in projects on GHG emission reductions, contributing both to the economic and environmental well - being of the country. Early efforts in developing a National Policy and technical framework included a National Policy Seminar on the CDM held in August 2002. It was attended by multi - stakeholders from the energy and industry, transport and the forestry sectors. Relevant Institutional issues, barriers and methodologies in the implementation of CDM projects focusing on the energy, transport and forestry sectors were discussed. Rahim (2005) provided a detail account of the Policy stand adopted in the National Seminar.

Institutional infrastructure

The Federal Cabinet established a National Steering Committee on Climate Change (NSCCC) in 1994. Subsequently in 31 May 2002 another body, National Committee on Clean Development Mechanism (NCCDM) was established. The Chairmanship and the Secretariat of the Committee was given to the Ministry of Science, Technology and Environment and two (2) Technical Committees support it. The Technical Committee on Energy (TCE) was chaired by the Ministry of Energy, Communications and Multimedia while the Ministry of Primary Industries chaired the Technical Committee on Forestry (TCF).

Since the changing of the Federal Cabinet structure in 2004, the Natural Resource and Environment Ministry (NRE), has been appointed as the Chairman (NRE's Secretary General) and the Secretariat for the NSCCC. The Ministry of Energy and NRE currently chair the TCE and TCF respectively. Among the tasks of the technical committees are to identify CDM project activities that meet national sustainable development criteria, design selection criteria, recommend the selection and approval of projects to the National Committee, monitor the implementation of projects and to accredit and register CDM service companies. The National Committee reports the progress and status of projects to the National Steering Committee on Climate Change. Recently, Malaysia has also notified its Designated National Authority (DNA) for the CDM. The DNA is now fully operational. Project proponents submit their project proposals to the National Committee on the CDM and these proposals are evaluated by either of the technical committees. The Institutional Structure on the CDM and the detailed functions of the NCCDM, the

Technical Committees and the Designated National Authority (DNA) are described further in **Appendix 2 and 3.**

Forestry carbon projects in Malaysia

There are already several energy projects in the country that have been approved by the DNA and registered in the Executive Board of the UNFCCC but none on forestry projects yet. It was partly because the forestry (A/R) projects have been given lower priority until recently as the modalities have only been approved in 2004 (Shamsuddin *et al.* 2005).

Carbon reduction forestry projects done during the pre – Kyoto period in Sabah by Innoprise Corporation Sendirian Berhad (ICSB) were the Innoprise-Face Foundation Rain forest Rehabilitation Project (Infapro) and the ICSB – New England Power (NEP) reduced-impact logging (RIL). Infapro is still being evaluated for submission to the relevant parties[5].

Eligibile forestry activities under the CDM

As provided under **Article 3.3** of the Protocol, in the initial COP negotiations, the forestry activities to be used by Annex I Parties in meeting their emission reduction commitments were restricted to the **afforestation, reforestation (A/R), deforestation** and **forest management** activities. Eventually the COP 7 held at Morocco decided to include only the **A/R** as the accepted forestry activities in the first commitment period (2008 –2012) under the CDM[6]. The COP would determine the modalities, rules and guidelines for using the **A/R** as provided under **Article 3.4.** Definitions and modalities for such forestry activities under the CDM were finally adopted in COP 9 for implementation in the first commitment period.

[5] The RIL project is not eligible for consideration under the Kyoto Protocol as NEP, is located in the United States of America (USA) which is not a party to the Protocol.

[6] Section 7. (a) of the Marrakesh Accords states that …. the eligibility of land use, land-use change and forestry project activities under the clean development mechanism is limited to afforestation and reforestation… (UNFCCC 2005)

A/R definitions

Under the adopted rules adopted by COP 7, the eligible **afforestation** activity is defined as the direct-human conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seedling and /or the human-induced promotion of natural seed sources.

The eligible **reforestation** activity on the other hand is defined as the planting of forest on land, which previously had forest but was seriously degraded prior to 1990. This means **reforestation** activities established simply after cutting down current forests as stipulated under the Sabah's SFM practices do not qualify as acceptable CDM forestry projects.

To be eligible, the CDM forestry project has to demonstrate a real land-use change from non-forest to forest, and thus prevent current forests from being converted into plantations. For example, the accepted CDM forestry projects should involve the conversion of agricultural, industrial, commercial or residential land to forest.

Additionality

The **"additional"** provision under **Article 6.1 (b) and 12.5 (c)** restricted further the usage for the **A/R** activities under the CDM. This means that to be eligible all forestry carbon projects must demonstrate that the GHGs reductions that occur in the project activity must be additional to what would have taken place without the CDM project. In other words to qualify for the forestry carbon offset projects under the CDM had to be those that were not meant for implementation under the normal forestry's **"business as usual"** (BAU) practices.

Eligible SFM activities

The implementation of Sustainable Forest Management (SFM) system in Sabah started at Deramakot Forest Reserve in 1989 in the collaboration with the German Agency for Technical Co-operation (GTZ). This reserve is a Class 2 Commercial Forest Reserve and managed in accordance with the principles of sustained yield and multiple-use forest management. It was certified by the Forest Stewardship Council as a well-managed forest in 1997. In the same year, the Sabah state government entered into Sustainable Forest Management Licence Agreements (SFMLA) with 13 different companies for the implementation of SFM in the state. Each of those agreements is in force for a period of 100 years covering specific Forest Management Unit (FMU) of about 100,000 ha of largely logged-over production forest.

Under the current forestry management requirements in Sabah, stipulated in the terms of the SFMLA, the preparation as well as the implementation of Forest Management Plan (FMP), the Comprehensive Harvesting Plan (CHP), reduced-impact logging (RIL), enrichment planting, silvicultural treatments, and other relevant forest management efforts are mandatory forestry activities and practices to be implemented by the SFMLA's holders. In the evaluation of the progress of SFM in Malaysia, all of these practices are also used either as indicators/verifiers or as activities and standard of performance. Such action reinforces further that these forestry activities are not "additional" to SFM as they formed the standard "BAU" practices for implementation in the country.

The recent development under the CDM therefore excludes the eligibility of the SFM activities widely practiced by the long-term sustainable forest management agreement (SFMLA) holders in Sabah (Rahim and Anuar, 2005)[7]. Under the rules recently adopted in COP9, the only eligible LULUCF activities in Malaysia are restricted to those that meet the definitions of the **A/R** and perhaps the **additionality** provision such as abandoned shifting cultivation areas, tin tailings, Bris soils as well as line/vacant land planting (Rahim 2005).

[7] The enrichment planting and forest plantation establishment activities, which formed part of the SFM standard practices in Sabah do not meet the established definitions for **A/R** under the CDM. To be eligible for funding under the Kyoto Protocol, all forestry carbon projects have to demonstrate that they are "**additional**" or new undertaking to the "BAU" under SFM and that they meet the definitions set for the **A/R** activities.

Opportunities for forestry carbon projects

Forest plays an important role in the carbon cycle by absorbing carbon dioxide and releasing oxygen to the atmosphere through the natural process of photosynthesis. Carbon dioxide is converted to carbon (sequestered) and stored in the woody tissue (biomass) of the plant. The rate at which carbon is sequestered varies by the site, age, management and species characteristics of the forest. Managing the existing forest resource including carbon sequestration and storage involves minimizing the loss of forest area due to deforestation, maintaining or improving tree growth, minimizing soil disturbance and residual stand damage during timber harvesting, ensuring satisfactory natural regeneration of harvested forest and forests damaged by fire, insects, and diseases; improving forest fire suppression and management capabilities; adopting reduced-impact logging practices; and minimizing the negative environmental impact of road construction.

In reality, the practice of SFM activities to sequester carbon by promoting forest establishment and growth, or to avert the loss of standing forest resources from land clearing, disease or fire should potentially be an important strategy for slowing climate change. However, unfortunately all types of carbon sequestration activities under SFM are not eligible for CDM support currently. Seeking fund from the Non–Kyoto Parties and the retail "green market" (also known as non–CDM funds) is an alternative, which the Federal government could consider as foreign direct investment (FDI) under the forestry sector. These, however, may only provide short-term solutions to the mega fund required for SFM implementation. Rahim and Anuar (2005) suggested some opportunities which the forestry sector in the state could adopt. By and large their suggestions may not be realized in the immediate term as they involve forestry and financial policy shifts at the state and Federal level. However, one of the suggestions involving capacity building in carbon expertise may be feasible to be taken up further in this workshop as it is in line with those under the NC2.

Conclusion

After numerous negotiations by the COP of the UNFCCC, the much awaited forestry role in the global climatic treaty had been limited to include only the A/R activities. Such restriction, together with the need for additionality assessment of carbon forestry projects under the CDM had excluded the eligibility of the SFM activities in Sabah. Under the current rules of the CDM, even the pre–Kyoto projects such as the Infapro may not be eligible. Given these constraints the only eligible forestry carbon projects would now appear to be confined to the afforestation of abandoned grass land areas or reforestation of non–forested areas largely existing outside the forest reserves. Opportunities to go forward for the forestry sector in playing an active role in the global climatic agenda appear to be limited and would involve the usual lengthy journey in policy changes. A viable option suggested for this seminar is to look at the need for capacity buildings of the Sabah Forestry Department.

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Appendix 1. <u>The Kyoto Protocol</u>

The Kyoto Protocol was adopted at COP-3 in Kyoto Japan in December 1997, bringing the international community a step closer towards the implementation of a global Climate Treaty. Under the Protocol, the UNFCCC member nations were divided into three large groups, namely The Annex I, Annex II and non-Annex I parties, each one given different responsibilities and role under the Protocol.

The Annex I parties include the 36 industrialised countries that were part of the Organization for Economic Co-operation and Development (OECD), plus countries with economies in transition ((EITs) such as the Russian Federation and several Central and Eastern European countries of the former Soviet Bloc)). Annex II parties (also known as Annex B Parties) are all the parties of Annex I not including the EITs. Non-Annex I parties include all other states party to the convention, mainly developing countries. They do not have any emission reduction target, as compared to both Annex I and II Parties.

The four main output of the Protocol were:

- The binding commitments by the Annex 1 countries to reduce their overall GHG emissions by an average of 5.2 % below the 1990 levels. The specific targets of reduction vary from country to country. There was no emissions target for the non-Annex 1 countries.
- The reduction should be undertaken over the period from 2008 and 2012, defined as the First Commitment Period.
- Three (3) market-based mechanisms, viz, International Emission Trading (EIT), Joint Implementation (JI), and the Clean Development Mechanism (CDM) were approved to facilitate these GHG emissions reduction targets. The CDM was the only mechanism that was achievement of allowed the participation of the non- Annex I countries (developing countries) in the climate change mitigation.
- Recognition of the Land use, Land use Change, and Forestry (LULUCF) activities under various sections of Article 3 as valid options for reducing net concentration of atmospheric GHG. Carbon offsets can also be generated by GHG reduction projects in the energy, construction, commercial, transport, industrial and other sectors.

The Kyoto Protocol was opened for ratification on March 16, 1998. The Protocol had entered into force on the 16th February 2005, after Russia's ratification had met the requirement of having at least 55 parties to the UNFCCC, including Annex 1 Parties representing at least 55 % of the total CO_2 emissions for 1990. To date, a total of 150 countries* had ratified the Protocol, including Annex 1 Parties, representing a total of 61.6 % of CO_2 emissions (UNFCCC, 2005). Malaysia signed and subsequently ratified the Protocol on 12th March 1999 and 4th September 2002 respectively. Being a Party to the Protocol, Malaysia is committed to the full implementation of the CDM in an equitable manner. Rahim (2005) gave further description of the current institutional infrastructure and the application procedures for CDM forestry projects in Malaysia.

* Unfortunately the United States of America (USA), which is responsible for an estimated 25% of the GHG emissions decided to stay out by its non-ratification of the Protocol in March 2001. The main reason was the Protocol would raise energy prices and cost five (5) million U.S. jobs. Australia adopted a similar stance not long after that.

Appendix 2. Institutional set up for CDM in Malaysia

1. Introduction

Recognising the importance of climate change and active involvement of the government in the activities related to the Convention, a National Steering Committee on Climate Change (NSCCC) was established in 1994 to oversee and address all issues related to climate change, the Convention and the Kyoto Protocol. The NSCCC has established a two-tiered organisation for Clean Development Mechanism (CDM) implementation in Malaysia (**Figure 1**). The NSCCC chaired by the Secretary General of the Ministry of Natural Resources and Environment (NRE) agreed on 31 May 2002 to:

- Establish a National Committee on CDM (NCCDM), its Terms of Reference (ToR) and membership and
- Establish two Technical Committees, namely on the Energy Sector (TCES) and the Forestry Sector (TCFS), respectively chaired by the Ministry of Energy, Water & Communications (MEWC) and the Ministry of Natural Resources and Environment (NRE).

The Conservation and Environmental Management Division (CEMD) at NRE is the Designated National Authority (DNA) for CDM in Malaysia. The DNA has been registered with the UNFCCC secretariat. The role of the DNA is to issue the Host Country Letter of Approval to the CDM project proponent. This letter is required before registration of the CDM project with the CDM Executive Board.

2. Role of NCCDM

- To review and recommend CDM project proposals that meet the national criteria for approval.

3. Terms of Reference (ToR) of NCCDM

- To develop policies, direction, strategy, criteria and guidelines for implementation of CDM projects at national level.
- To receive, evaluate and recommend CDM project proposals after obtaining comments and views from the Technical Committees.
- To monitor CDM projects and inform its status from time to time to the NSCCC.
- To hold meetings of the NCCDM at least four times a year.

4. Membership of the NCCDM

1. Deputy Secretary General (Policy), Ministry of Natural, Resources and the Environment - **Chairman**
2. Conservation and Environmental Management Division, NRE - **Secretariat**
3. Malaysian Meteorological Service
4. Ministry of Plantation Industries and Commodities
5. Ministry of Energy, Water & Communications
6. Economic Planning Unit
7. Ministry of International Trade and Industry
8. Ministry of Transport
9. Centre for Environment, Technology and Development
10. Forestry Division, NRE

5. Terms of Reference (ToR) for Forestry Technical Committee

1. To provide policy guidance on CDM projects to the National Committee on CDM
2. To ensure that CDM project proposals comply with national criteria and guidelines for CDM projects
3. To undertake technical evaluation of the CDM Project Idea Notes (PINs) and Project Design Documents (PDDs)
4. To recommend and submit evaluated CDM project proposals to the NCCDM for consideration
5. The Technical Committee shall meet at least 4 times a year.

6. Members of the Technical Committee for Forestry CDM Projects

- Undersecretary (Forestry Division) Ministry of Natural Resources and the Environment - **Chair**
- Forest Research Institute Malaysia (FRIM)
- Forestry Department Peninsular Malaysia

- Forestry Department Sabah
- Forestry Department Sarawak
- Malaysian Palm Oil Board
- Malaysian Rubber Board
- Malaysian Agriculture Research Development Institute
- Ministry of Plantation Industries and Commodities
- Environmental Protection Society Malaysia
- Malaysian Nature Society
- CEMD
- Pusat Tenaga Malaysia
- **Secretariat** – FRIM

7. FRIM as the CDM Secretariat for CDM Forestry Project

Although FRIM has been assigned as the secretariat for considering application of CDM projects on forestry, it has not been operational yet. This is partly due to the fact that the rules and modalities for forestry projects had only been agreed in the last COP 9 and 10 Meetings in 2003 and 2004 respectively. FRIM has assigned the International Unit to take the role of the Secretariat and is in the process of assigning key personnel.

8. Proposed Terms of Reference (ToR) of Forestry CDM Secretariat

The Secretariat will provide support to the CDM Technical Committee for Forestry in carrying out its duties. In addition, to foster and promote CDM project development, the Forestry Secretariat acts as a resource centre on CDM in providing the following assistance:

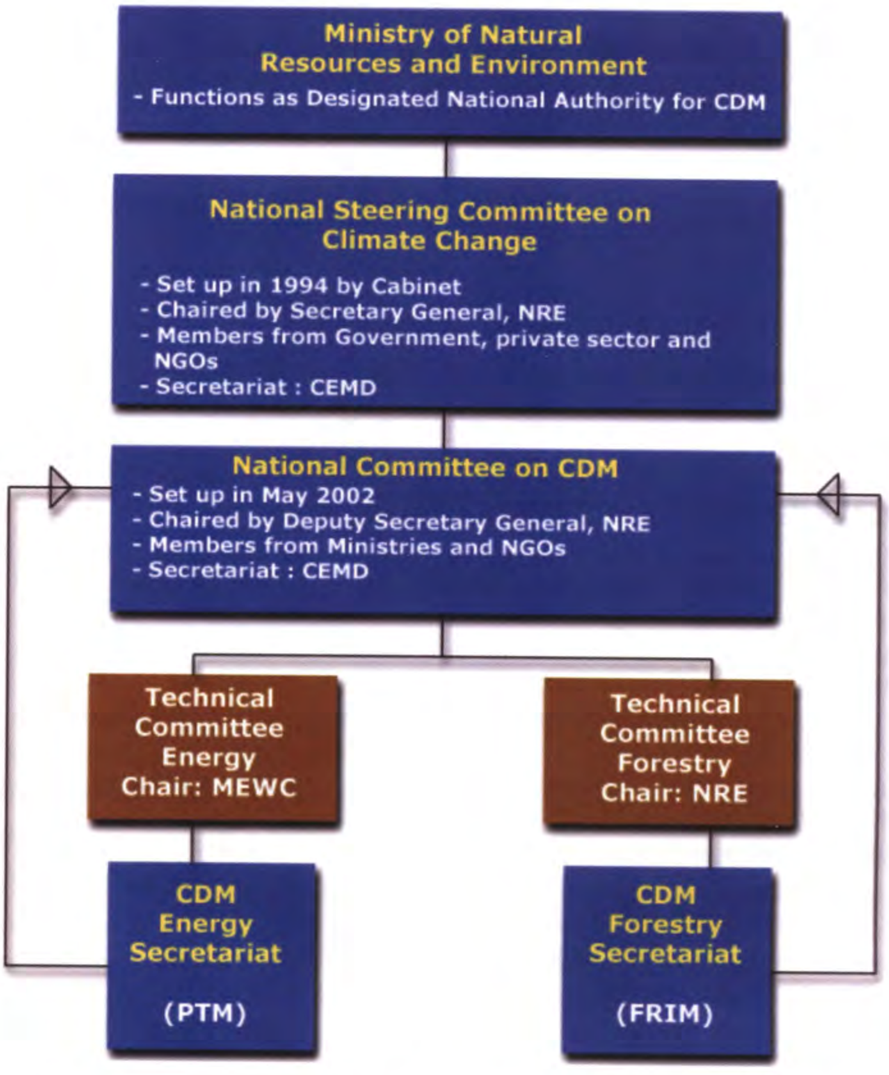
- Provide background materials needed on all aspects of the CDM project cycle including internationally approved guidelines for baselines studies and monitoring procedures.
- Assist the Technical Committee by setting up a national website on CDM projects activities.
- Provide inputs to the formulation of the CDM forestry policy and promotional strategy (i.e. formulation of methodologies, such as baseline setting, assessment of needs for capacity building assessment of CDM potential in Malaysia).
- Create a national database on the major stakeholders in CDM forestry project development.
- Create awareness and disseminate information (through the website, media and organisation of events, such as seminars and stakeholder meeting).
- Document and monitor successful projects and "good practices".
- Network with national stakeholders and identify local experts.
- Provide advisory services to foreign and local investors and developers in the identification and development of project proposals.
- Conduct technical evaluation of CDM project proposals

9. Application for CDM Projects

Project developers are required to submit the Project Idea Note (PIN) as the preliminary screening document to the DNA, which is the Conservation and Environmental Management Division (CEMD) of Ministry of Natural, Resources and Environment (NRE), which carries out the initial screening. For forestry projects, the PIN will be forwarded to FRIM for technical evaluation of the project. The CDM Forestry Secretariat in FRIM may liaise with the project developer for more details and/or clarification. It will then carry out the technical evaluation with assistance of a Task Force, if necessary. The Technical Committee will review the technical evaluation and recommendations of the CDM Forestry Secretariat and forward its finding and recommendations to the National Committee on CDM (NCCDM).

The NCCDM bases its decision on the recommendations and opinion of the Technical Committee. If the NCCDM finds that the proposed project complies with all the national requirements, a conditional letter of approval will be issued by the DNA. This authorises the project partners to take part in a CDM project. **Figure 2** shows the various stages an application for CDM project would have to go through.

The Ministry has indicated to FRIM that the secretariat will have to be operationalised. In this regard, they have contacted the Danish embassy to explore possibilities of providing some assistance similar to that DANIDA is currently providing to Pusat Tenaga Malaysia, which is the secretariat for CDM energy projects. It was indicated that DANIDA is willing to support FRIM in capacity building and other assistance in operationalising the secretariat. However, they would like to see a specific Unit being set up to support the secretariat for this purpose. Further discussion will proceed once FRIM agrees to formally set up the secretariat.



CEMD: **Conservation and Environmental Management Division**
MEWC: **Ministry of Energy, Water and Communication**
PTM: **Pusat Tenaga Malaysia**
FRIM: **Forest Research Institute of Malaysia**
NGOs: **Non-Governmental Organisations**

Figure 1. The set-up of the CDM national institutional arrangement.

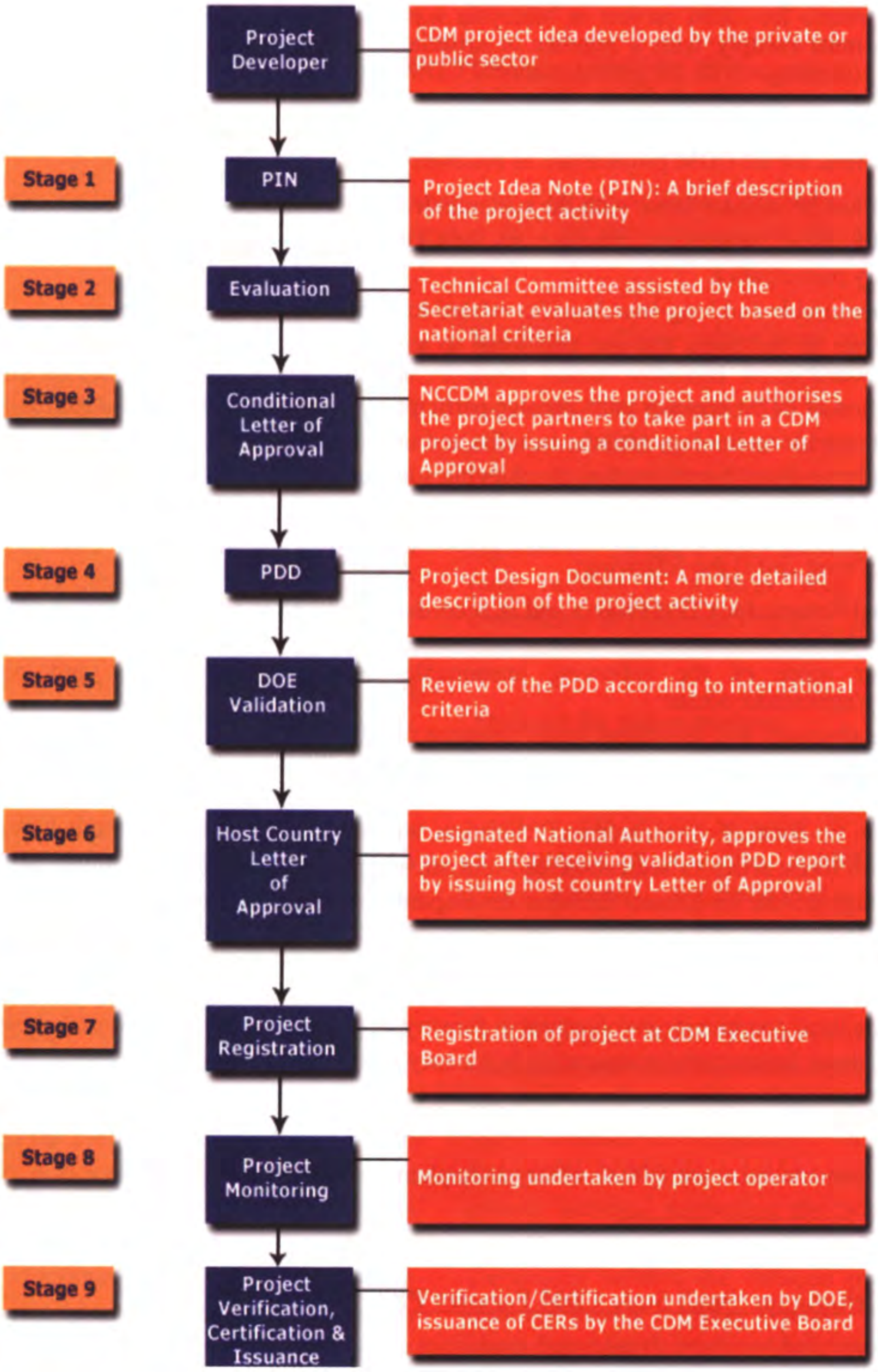


Figure 2. Various stages a CDM project will have to go through.

Appendix 3. Criteria for forestry CDM projects

A. Introduction

The national Criteria for CDM project in Malaysia was formulated by the NCCDM on 15 August 2003. CDM projects must comply with a number of criteria as stated below. Approval of a CDM project is conditional on compliance with the general national CDM criteria.

B. General National CDM Criteria

The national criteria for all CDM projects are as follows:

1. The project must be in accordance with the sustainable development policies of the government;
2. Project must fulfill all conditions underlined by the CDM Executive Board as follows:
    a. Voluntary participation
    b. Real, measurable and long-term benefits related to mitigation of climate change;
    c. Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.
3. Implementation of CDM projects must involve participation between Malaysia and Annex 1 Party/Parties;
4. Project must provide technology transfer benefits and/or improvement in technology;
5. Project must bring direct benefits towards achieving sustainable development

C. Proposed Criteria for CDM Forestry Projects for Malaysia

Forestry project must fulfill the following;

- National Criteria for CDM Project and in accordance with rules and modalities as agreed by the COP of the UNFCCC.
- One or more of the following sustainable development strategies and policies of the forestry/agriculture sector:
- Ensure adequacy and security of wood resource supply;
- Promote the establishment of forest plantations of indigenous and exotic species to supplement timber supply from the natural forests;
- Promote the conduct of research and education, and the conservation of biological diversity;
- Establish forest areas for recreation, eco-tourism and public awareness and education;
- Encourage private investment in forest development through the development of forest plantations in private on non-forested lands;
- Promote establishment of community forests to cater needs of the rural and urban communities through eradication of poverty and diversification of income sources;
- Promote local community involvement in forestry development and agro-forestry programmes;
- Foster closer international cooperation in forestry and to benefit transfer of technology.
- The project shall conform to the environmental legislations/regulations of Malaysia.
- The project proponent should justify that the project utilizes the best available technologies.

The project proponents must justify their ability to implement the proposed project based on the following:

- Locally incorporated company
- Likely sources of financing the project

D. Proposed Criteria for Small Scale CDM Forestry Projects

Small-scale project has to adhere to rules and modalities as agreed by COP 10 of UNFCCC. Amongst others they include:

- The threshold of 8000 tonnes CO_2 sequestration per annum is based on the estimated average level during the first verification period. If actual sequestration is higher, only 8000 (T)CERs/(L)CERs will be issued per annum.
- No adaptation tax is to be paid and registration and administration fees will be reduced

Landscape-level evaluation of carbon and biodiversity in the tropical rain forests of Deramakot Forest Reserve, Sabah, Malaysia

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Abstract Site-based measurements of biomass (and carbon) are the accurate method but costly in time, budget and manpower. The application of remotely sensed data may achieve our goals in a large area in the shortest time. We investigated how remotely-sensed data could be applied to estimate above-ground biomass in the production forests of Deramakot Forest Reserve (reduced-impact logging site) and Tangkulap Forest Reserve (conventional logging site as of the analysis). We converted the tree census data from the research plots, which had been established by 2003, into above-ground biomass with the use of standard allometric equations. Altogether, we employed the data from 51 plots. We accurately measured the four corners of each plot with a GPS (Global Positioning System) equipment. We added three plots devoid of any tree cover as reference points. Subsequently, the location of each plot was determined on the LANDSAT ETM data taken in 2002. Among various combinations of LANDSAT bands, the normalized index of band 4 and 5 (called NDSI) demonstrated the highest correlation with the biomass values estimated from the ground data. However, the biomass estimates from this correlation model saturated at biomass 500 ton/ha or greater. This causes a considerable underestimate of biomass in high stock forests. We therefore numerically corrected the biomass values, where reflectance signals were saturated, using the canopy heterogeneity as guidance; in this algorithm we added proportionately greater correction values, with increasing canopy homogeneity, to the biomass values estimated from the correlation model. Application of this method to Deramakot and Tangkulap yielded the mean biomass density of 347 ton/ha in Deramakot, and 293 ton/ha in Tangkulap. These values were comparable to the mean values obtained from the ground survey, suggesting the adequacy of our methods. The difference of the two mean values (54 ton/ha) can be attributed to the difference in the logging methods. The cautious use of our methods can legitimately evaluate the above-ground biomass (and carbon) in a large area in the mixed dipterocarp tropical rain forests of this region.

Abstract for policy-makers

We investigated how effectively remotely-sensed satellite data could be used in the sustainable management of production forests in Deramakot Forest Reserve. We developed a new method to estimate above-ground biomass (equivalent to volume stock) in a large area using Landsat satellite data. The method and applications are described in this paper. With the use of this method, the mean biomass value was estimated to be 347 ton/ha in entire Deramakot (all compartments combined), and 293 ton/ha in Tangkulap. These values were comparable to the mean values obtained from our ground surveys, suggesting the adequacy of our method. The greater mean value by 54 ton/ha in Deramakot reflects the reduced impacts by RIL (reduced-impact logging) system. The use of our method can legitimately evaluate the above-ground biomass (and carbon) of the mixed dipterocarp tropical rain forests of this region on a landscape level, and therefore may be applicable to other Forest Management Units of similar forest types. Moreover, our method can rapidly evaluate canopy heterogeneity (which we consider as an index of the overall forest health) in a large area. As canopy

heterogeneity can become a surrogate for the abundance/richness of certain organisms (trees and mammals for instance), our method has a great potential to be used in the auditing system of forest certification to evaluate biodiversity in addition to the usefulness in stock and biomass estimation. As more forests are certified, timber prices are expected to fall. A new scheme to qualitatively and quantitatively ordinate certified forests is needed in order to differentiate better-managed forests from the rest. The amount of remaining carbon and biodiversity in logged-over forests are the two indicators to ordinate the forests and our method can evaluate these two indicators in a large area.

Keywords biodiversity, biomass, canopy heterogeneity, carbon, satellite data, tropical rain forests, reduced-impact logging

Introduction

Tropical rain forests are the reservoir of carbon. A web of organisms is maintained through carbon (energy) and mineral flows in a given rain forest ecosystem. Carbon (energy) and mineral flows include a grazing chain that starts from live plant parts (biomass) and a detritus chain that starts from dead plant parts (necromass). In either case, plants provide dependent organisms with carbon as food resource. Dependent organisms, on the other hand, maintain plant populations through pollination and mineral recycling. Biodiversity and carbon are thus intimately related to each other. It is logical to infer that biodiversity should maintain the long-term stability of tropical rain forests. This intuitive notion, however, is not well substantiated in the filed, particularly in tropical rain forests. One reason why we focus on the linkage between carbon and biodiversity lies in this academic challenge.

Secondly, carbon and biodiversity are the two major issues in the contemporary forestry (Scherr *et al.* 2004). Forests are expected to sequester carbon as biomass and thus to contribute to the reduction of green house gases. There are markets for carbon trading and, in this sense, forests have a new economic value. At the same time, forests are expected to contribute to the conservation of biodiversity. It is needless to say that the maintenance of natural forests can achieve both carbon sequestration and biodiversity conservation. However, the natural forests are fairly limited in extension in the modern landscapes. In the tropics, logged-over forests predominate the landscape and natural rain forests are confined to protected areas. In this context, logged-over forests are the key area to control the carbon budget and biodiversity conservation. Tropical foresters are expected to achieve the synergy between carbon sequestration and biodiversity conservation in production (largely logged-over) forests. This is the second reason why we are concerned with carbon and biodiversity.

The ultimate goals of the collaborative Malaysia-Japan project in Deramakot Forest Reserve, Sabah, Malaysia, are to establish techniques how to maintain carbon and biodiversity in production forests. Logging obviously reduces the amount of the carbon left in production forests by extracting timber. However, reduced-impact logging (RIL) can maintain a relatively high carbon stock while maximizing yields (either monetary or volumetric yield in a longer term). In this paper, we first describe the methods to evaluate carbon and biodiversity in a large area using satellite data. We, then, demonstrate how effectively RIL in Deramakot can maintain above-ground carbon at a landscape level by comparing with the carbon stock in the surrounding Tangkulap Forest Reserve where conventional logging has been applied. Site-based measurements of biomass (and carbon) are the accurate method but costly in time, budget and manpower. The application of remotely sensed data may achieve our goals in a broad area in the shortest time. This report describes some new algorithms to apply remotely sensed data in biomass/carbon estimate, and subsequently some conceptual frameworks to incorporate carbon and biodiversity into sustainable forest management.

Methods

Biomass estimation

New algorithms to estimate above-ground biomass were developed by Nakazno *et al.* (in prep. in Japanese), in which the authors coincide with those of the present paper. Herewith, we briefly describe the methods. We used ground-based data from 43 plots located in Deramakot and two plots in Tangkulap. The imagery of the study area is shown in Fig. 1. Those plots consisted of ten 0.2 ha quadrats (20 x 100m or 40 x 50m) and thirty-five 0.16 ha quadrats (20 x 80m). Tree censuses were conducted in these plots for those trees more than 10cm diameter at breast height (dbh) by the FRC team or the Japanese team. All trees more than 10cm dbh were identified to species with their dbh values measured. We converted dbh values into above-ground biomass values using the following standard allometric equations (Brown 1997):

$$Wt = \exp(-2.314 + 2.53 \times \ln(dbh)) \qquad (1)$$

Here, Wt (kg) is above-ground biomass inclusive of leaves and branches, and dbh (cm) is diameter at breast height.

In order to identify the locality of each plot, we measured the longitude and latitude of the four corners of each plot at the resolution of 0.001 minute using a global positioning system (GPS) (Magellan Meridian Platinum, USA). When we judged that the readings of GPS had some errors due to the interference from a thick canopy, we corrected the position readings based on the land survey data on the ground.

In addition to forest plots, we added two plots in grassland and one plot in bare land (each 0.09ha of 30x30 m) in order to get reference points for low-biomass signals. The positions of each plot were determined as above.

We used Landsat ETM data taken on May 28, 2002, for the analysis of remotely sensed data. Landsat ETM consists of eight multi-spectral sensors and has 30 x 30m resolutions. This means that one pixel on the data corresponds to the ground area of 30 x 30 m. Tropical rain forests are often covered by thick clouds and reflectance data captured by Landsat ETM thus cannot correctly reflect the canopy conditions. The data that we used also demonstrated cloud effects, but we judged that none of our plots are under the clouds.

In the vegetation analysis of the satellite data, normalized vegetation index (NDVI) is often used. This index is based on the nature of green plants on which chlorophyll absorbs red radiation (R), and reflects near-infrared radiation (IR). The difference of the strength of absorption of R and reflectance of IR is normalized by the total radiation of R and IR as follows:

$$NDVI = (IR - R) / (IR + R) \qquad (2)$$

In the Landsat ETM data, R corresponds to band 3 and IR to band 4. This index is useful for the ecosystems of low vegetation coverage. However, NDVI can quickly saturate above a certain threshold value of vegetation coverage. In order to resolve this problem, we used another index called "NDSI" as follows (Nakazono *et al.* in prep.):

$$NDSI = (band4-band5) / (band4+band5) \qquad (3)$$

NDSI is a normalized index of the reflectance from bands 4 and 5 of Landsat ETM. We compared the calculated NDSI indexes of the research plots and the biomass values estimated from the ground data using the allometric equations. NDSI indexes increased curvi-linearly with increasing above-ground biomass values estimated based on the allometric equations among 37 research plots (Fig. 2). The slope of NDSI values for initial biomass values was steep and NDSI quickly saturated at greater biomass values. We fitted biomass values to NDSI based on the following equation:

$$B = 1040.5 \times (NDSI)^{0.5} - 78.885 \qquad (4)$$

where B is above-ground biomass (ton/ha).

We predicted that the biomass values based on the reflectance data of Landsat ETM could be overestimated than those values based on the allometric equations. This overestimation can occur because the forests of a re-growth phase during a secondary succession are characterized by disproportionately greater foliar biomass (and thus greater leaf area index) than wood biomass leading to a disproportionately greater reflectance signal of biomass, i.e. overestimation of total above-ground biomass. In order to correct this overestimation effect, we identified the forests where the overestimation was likely to occur. Once again, such forests are at a re-growth phase and those forests are often characterized by heterogeneous canopy conditions because timber extractions cause patchy canopy openness, which is visible throughout the re-growth phase. On the other hand, the natural forests or the logged-over forests after reduced-impact logging may have more homogeneous canopies. We, therefore, categorized forests into several canopy-heterogeneity conditions following the methods of Nagatani *et al.* (2000). Firstly, we removed the pixels affected by clouds, open-water and bare soils, and then categorized the remaining pixels into 256 classes based on an unsupervised classification method. Subsequently, we calculated the number of classes included within a varying mesh size (n x n pixels from any one point; n was always odd number; one pixel corresponds to 30 x 30 m). We defined the number of classes in a n x n mesh as F(n), which reflected the canopy heterogeneity condition, i.e. greater the F(n) is, more heterogeneous the canopy is. We changed n from 3 to 15 and examined the changing pattern of F(n) in the following three training areas: Kuamut Forest Reserve where no sign of logging was visible; Deramakot Forest Reserve where timbers were mildly extracted by reduced-impact logging operation; and Tangkulap Forest Reserve where timbers were heavily extracted by conventional logging methods. We placed grids of 3000 x 3000 m in Tangkulap Forest Reserve and Deramakot Forest Reserve, and grids of 2000 x 2000 m in Kuamut Forest Reserve as demonstrated in Fig. 3.

When we changed n from 3 to 15 at each of the grid points in the three training areas, F(n) values changed rapidly as depicted in Fig. 4 (two sites only are shown). Notably, F(n) increased from Kuamut to Deramakot to Tangkulap at any n value, suggesting that canopy was more heterogeneous with increasing logging intensity. As explained earlier, biomass based on the equation (4) may be overestimated in heavily logged forests. We, therefore, categorized forests based on F(n) where n was set to 9 (pixels) and corrected biomass values as follows:

When F(9) $\geqq$ 25, the forest was considered heavily logged; B(corrected)=B - 50.

When F(9) < 25, and $(NDSI)^{0.5} < 0.4$; B(corrected) = B.

When $(NDSI)^{0.5} \geqq 0.4$, B values were saturated. In this case, we assumed that lower the F(n) value was, greater the B(corrected) value was. Thus, when F(9) $\leqq$ 11, B(corrected) = B + 200; when F(9) = 12, B(corrected) = B + 150; when F(9) $\leqq$ 14, B(corrected) = B + 100; when F(9) = 15, B(corrected) = B + 50.

Subsequently, at each intersect of the grids in the three training areas, we calculated biomass value based on the equation (4) (see below) and corrected by F(n) values as explained in the above. The mean value of the estimated biomass in each training area was then compared with actually measured biomass on the ground to investigate the accuracy of our methods.

Analysis of canopy heterogeneity and biodiversity

As has been stated, the mode of logging operation may result in different canopy heterogeneity. In the above analysis, canopy heterogeneity is expressed by the number of vegetation classes per unit area (i.e. F(n) where n ranges from 3 to 15 pixels corresponding to 90 x 90 to 450 x 450 m mesh). F(n) value will increase as unit area increases because F(n) is a cumulative value. There is another aspect in canopy heterogeneity, that is the deviation from a mean. The same number of vegetation classes may not occur if the area of analysis is spatially shifted in the forest where canopy heterogeneity is great. On the other hand, a similar (or the same) number of vegetation classes always occurs regardless of the locality if the forest is homogeneous. This spatial repetition can be demonstrated by the coefficient of variation (CV) of F(n). We, therefore, calculated the CV of F(n) with varying pixel sizes in Deramakot and Tangkulap. We hypothesized that CV of F(n) is greater at small unit area in Deramakot due to natural gaps and/or small-scale operations of reduced-impact logging, but thereafter CV decreases with increasing unit area. On the other hand, CV of F(n) can be greater at any unit area in

Tangkulap than in Deramakot, and will increase with increasing unit area in Tangkulap due to the large-scale operation of heavy logging.

Results

The estimates of above-ground biomass at the intersections of the grids in Deramakot and Tangkulap are indicated in Fig. 5. With increasing area (i.e. increasing pixel sizes) at the intersections, mean values of biomass are merged to a constant value in each site (Fig. 5). The mean value eventually became 346 ± 40 ton/ha in the Deramakot training area, and 273 ±25 ton/ha in the Tangkulap training area. These values are closely comparable to the actually measured values by Seino *et al.* (see this volume); this correspondence suggests that our method is robust enough to evaluate above-ground biomass.

We applied the equation 4 with the corrections described above to all compartments of Deramakot Forest Reserve to estimate above-ground biomass of trees. Results are shown in Appendix 1. Above-ground biomass density (ton/ha) by compartment of Deramakot Forest Reserve ranges from 285 (Compartment 134) to 480 (Compartment 110) with the mean value of 347. The total above-ground biomass in entire Deramakot Forest Reserve is estimated to be 19,038,000 tons as of May 28, 2002, the date of the satellite data. By contrast, the mean value of above-ground biomass densities at the intersects of 3000 m grids in Tangkulap Forest Reserve is 273 (ton/ha).

CV of F(n) values, i.e. an index of canopy heterogeneity, peaked in an area equivalent of 3 x 3 pixels (90 x 90 m) in Deramakot and then decreased with increasing area (Fig. 6); this suggests that a mean patch size of the canopy is nearly 90 x 90 m. Contrary, CV increased monotonously with increasing area up to 15 x 15 pixels in Tangkulap, indicating that canopy condition at the scale of 450 x 450 m varied from place to place.

Discussion and application

Biomass estimation on a landscape level

We suggest that the method described here can adequately estimate the above-ground biomass of the mixed dipterocarp tropical rain forests of Deramakot and the adjacent areas. The difference of biomass density by 54 ton/ha (347-293=54) between the two forest reserves is striking. It is very obvious that this difference is caused by the difference in the logging methods. We conclude that reduced-impact logging (RIL) is effective to reserve above-ground biomass by 54 ton/ha on average. We estimate that the net additive effect of the implementation of reduced-impact logging for the total area of Deramakot is 2,978,034 tons of biomass (54 ton/ha x 55,149 ha). This translates to the net addition of 1,340,115 tons of carbon assuming the concentration of carbon is 45% in biomass.

We applied our method to the entire region of Deramakot and Tangkulap, and mapped the distribution of biomass density at the resolution of 30 x 30 m. The color map in Fig. 7 contrasts Deramakot with the surrounding regions in terms of biomass density. It is noteworthy that this map can be used as a base map for forestry operation planning.

Implications for biodiversity

Above-ground biomass is significantly correlated with the number of families per 0.2 ha (r^2 = 0.55, P = 0.0138; Seino *et al.* unpublished). This correlation does not imply that richness is functionally linked to biomass and that family-rich forests are more stocked. It simply means that more severely logged forests are impoverished in the number of families of canopy trees. Thus, this correlation is applicable only to the logged-over forests in this region. Based on this assumption, we extrapolated this correlation to the entire region of Deramakot and Tangkulap. The number of families of canopy trees was estimated from the above-ground biomass. Results are indicated in

Fig. 8 for the years 1985 and 2002. The family richness has drastically changed between the two years. A large tract of Tangkulap and the adjacent areas were converted, and lost family richness, while the Deramakot region reserves family richness reasonably well. A large area in the Deramakot region demonstrates the increase of family richness obviously due to the recovery of biomass. The summary of the comparison is demonstrated in the bar graph of Fig. 9, which depicts the number of pixels categorized in each family-richness class (number of families per 0.2ha). During the seven years from 1985 to 2002, the frequency of richest classes (≧28 families/0.2ha) greatly decreased, while the frequency of modestly rich classes (22 – 27 families/0.2ha) increased. During this period, reduced-impact logging was introduced to Deramakot. Therefore, the results imply that reduced-impact logging system can preserve modestly rich assemblages of canopy-tree families, and sustain highest richness in places. We are in the midst of analyzing the patterns of the richness of other organisms (flying insects, soil fauna and mammals) with the anticipation that some groups of organisms (either abundance or richness) may correlate with above-ground biomass. If so, we can correlate the richness or abundance of such organisms with satellite reflectance data, and extrapolate landscape-level patterns to a large region.

Implications for the sustainable management of the tropical rain forests

Our analysis demonstrated that reduced-impact logging (RIL) was effective to sustain carbon in above-ground biomass, and modestly rich assemblages of canopy species. As such, our analysis is applicable to understand landscape-level patterns and processes with some assumptions. With this analytical ability, remotely sensed data and the algorithms described here can be effectively utilized in the sustainable management of tropical rain forests. Particularly, it is useful for a rapid evaluation of volume stock, designing logging roads/feeder roads/skit trails, post-harvest planning, auditing purposes for forest certification, wildlife conservation, spotting encroachment, and designing a cohabitation scheme with traditional villages. We, however, have to be cautious because our algorithms are applicable only to the logged-over mixed dipterocarp tropical rain forests with biomass ranges similar to ours. They may not be applicable to the other types of tropical rain forest such as montane forests or lowland forests of different canopy composition because reflectance signals will be different in such forests.

One of the key issues in the sustainable forest management is the incorporation of biodiversity. There may be at least two ways to apply remote sensing in the use of biodiversity for sustainable forest management. Currently, biodiversity is one of the criteria for sustainable management, and any indicators for biodiversity criteria are under rigorous search (see other papers in this volume). Furthermore, such indicators must be easily measured without expert knowledge and practically used in an auditing system yet with solid scientific bases. In this regard, remote sensing may be a good tool for spatially elucidating such indicators. As we have demonstrated, if the richness of tree families were valuable indicators for the biodiversity criteria, then we can make use of our algorithms to demonstrate the patterns of tree families in production forests. A prerequisite for such application is that the richness of tree families has an indicator value for overall biodiversity and ecosystem health. Secondly, biodiversity may be more positively incorporated into the management of production forests in such a way to add economic values to produced timbers. We here suggest a novel approach in the application of remote sensing in the use of biodiversity for adding such economic values.

The foundation of the market mechanisms why forest certification and reduced-impact logging work is primarily the ethic value added to certified forests. Conscious consumers recognize green premium values in certified forests and drive away the products from uncertified forests. If biodiversity can add further values for the certification system, such a management system can become a strong economic incentive for foresters and other related stakeholders. We suggest that economic values be added to timbers as follows:

Additional economic value = net carbon reserve (additionality) by RIL * unit carbon price in the market + net biodiversity additionality by RIL * market price for biodiversity (or price for ecosystem services that biodiversity can bring about) (5)

In this concept, the most challenging task is to determine the market price for biodiversity; this cannot be readily determined for obvious reasons. On the other hand, net biodiversity increase (additionality) by RIL can be spatially estimated by remote sensing with cautious assumptions.

As has been demonstrated, different modes of logging operations resulted in different canopy conditions. Reduced-impact logging (RIL) has created small canopy patches in the scale of 90 x 90 m, more-or-less close to the canopy conditions of pristine forests where natural canopy gaps only are visible. By contrast, conventional heavy logging created highly heterogeneous canopy conditions as large as 450 x 450 m or larger. Homogeneous canopy conditions are known to maintain the abundance of certain mammal groups (Johns 1997). According to our algorithms, the CV (coefficient of variation) of F(n) can effectively demonstrate the canopy homogeneity. As the inverse of CV is proportional to canopy homogeneity, the equation (5) can be rewritten as:

Additional economic value = net carbon sequestration by RIL * unit carbon price + 1/CV * market price for biodiversity (6)

Once again, at this moment, we are far from actually using the equation (6) because the environmental-economics to determine market price for biodiversity are still premature. However, the equation (6) can be readily applied to the auditing system of forest certification. Moreover, this concept can be used to differentiate better-managed forests from the rest even among certified forests. As the number of certified forests increases drastically, we need to invent another system to ordinate certified forests. It is logical to assume that the price of timbers will eventually fall if the number of certified forests increases. For this purpose, our algorithms and the equation (6) are quite powerful to add another green-premium value to well-managed forests with rich biodiversity of the organisms, provided that such organisms are sensitive to canopy openness.

One of the remaining research tasks is to substantiate how effectively canopy homogeneity reflects the abundance and diversity of various organisms. In the next phase of the collaborative Malaysia-Japan project, we need to focus on this research question. Secondly, we suggest that our algorithms be actually applied in the auditing of forest certification in the near future.

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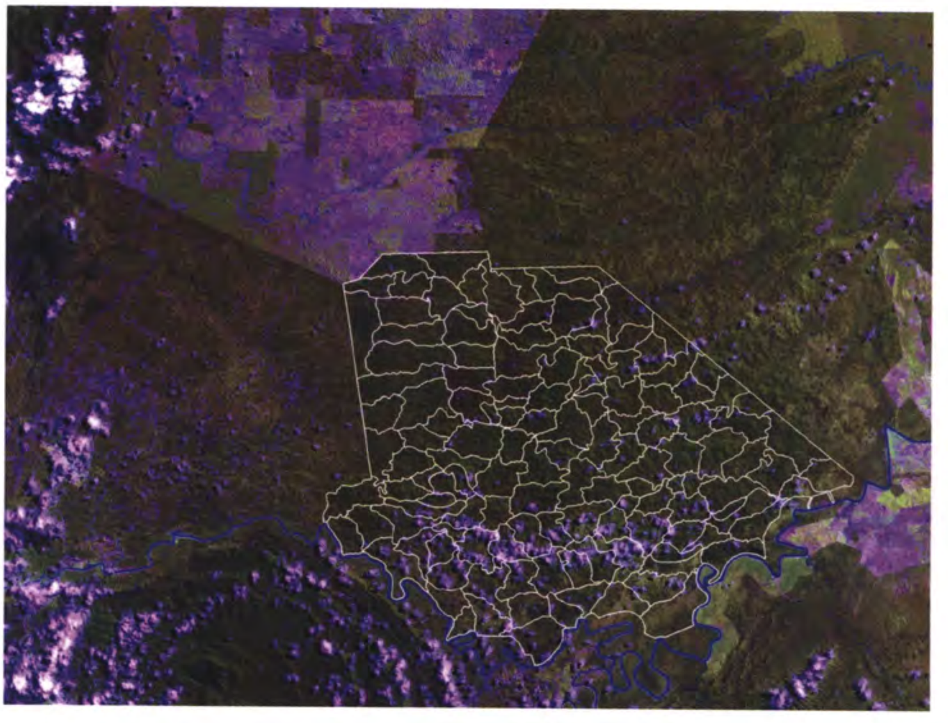

Figure 1. The aerial view of Deramakot Forest Reserve, Tangkulap Forest Reserve and the adjacent areas. The view is shown with Landsat ETM data as of May 28, 2002.

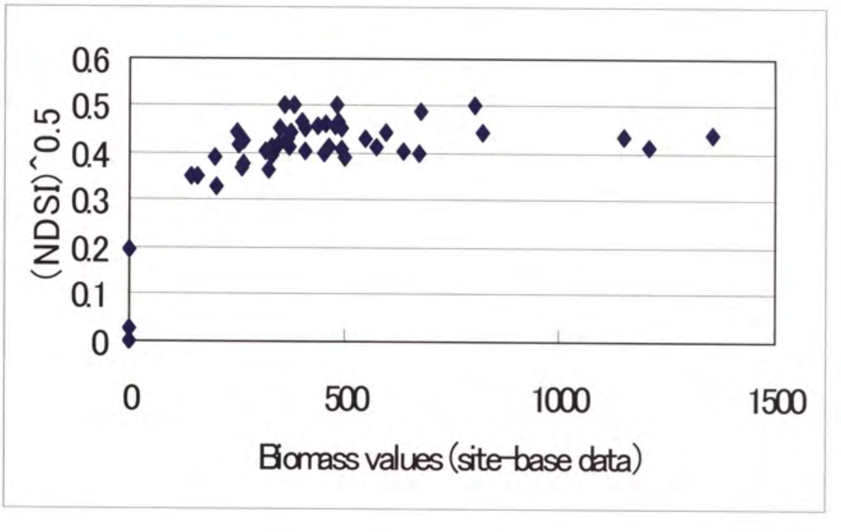

Figure 2. The relationships between NDSI and measured above-ground biomass among ground research plots.

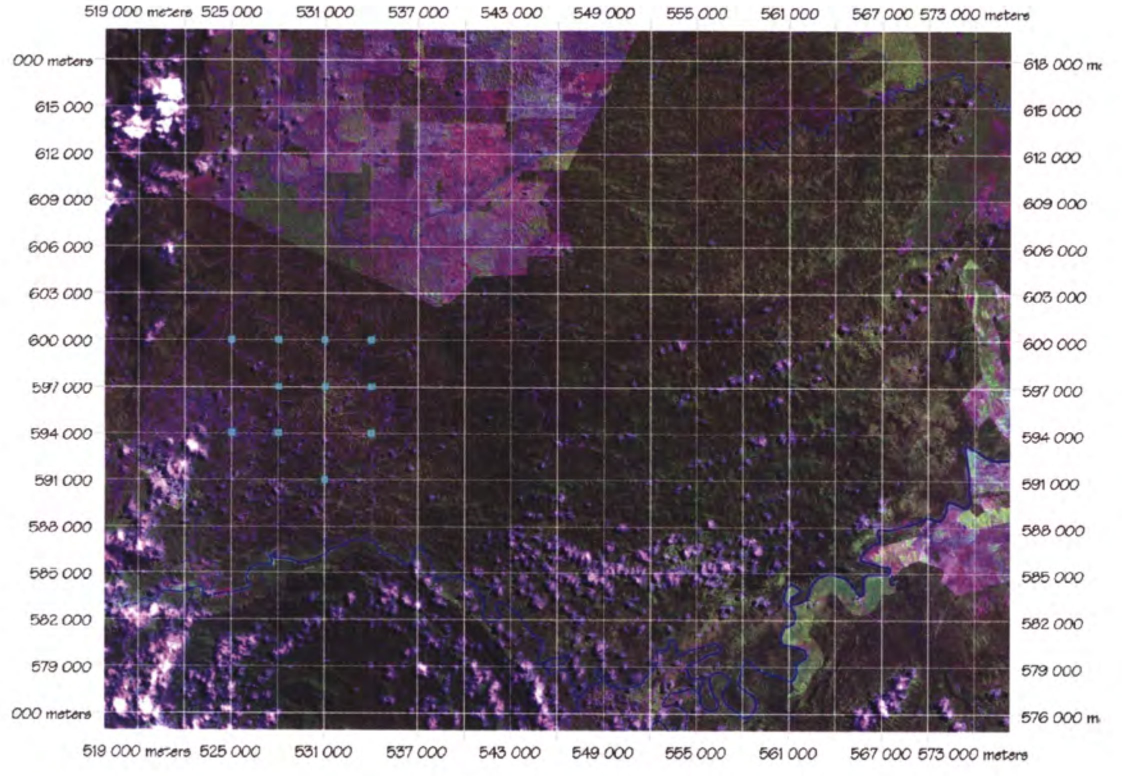

Figure 3. An example of the grids placed in the three training areas.

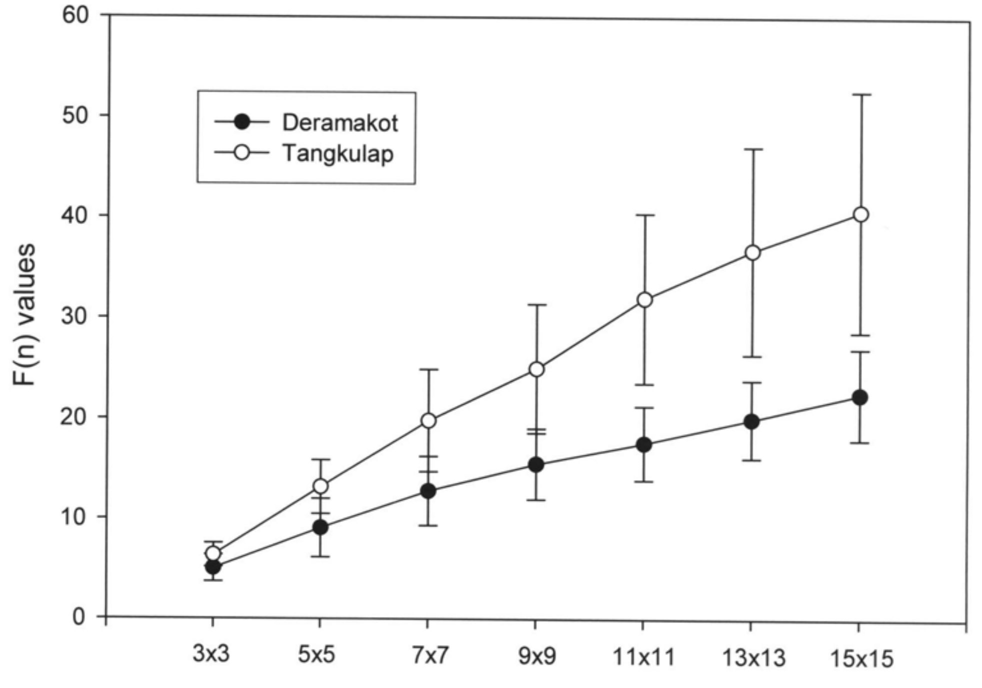

Figure 4. The number of classified vegetation classes per unit area, and increasing patterns with increasing unit area. The number of vegetation classes is expressed as F(n); see text for the details.

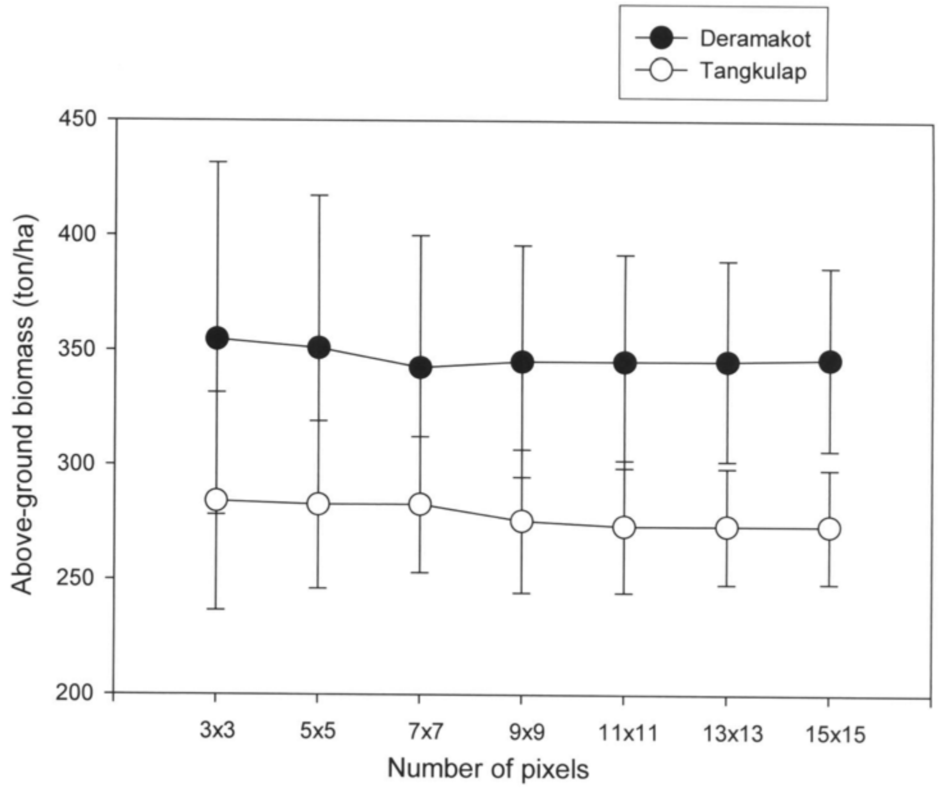

Figure 5. Mean ± SD of estimated above-ground biomass densities (ton/ha) based on NDSI with numerical corrections. Biomass densities are evaluated with increasing unit area at the intersections of the grids (see Fig. 3).

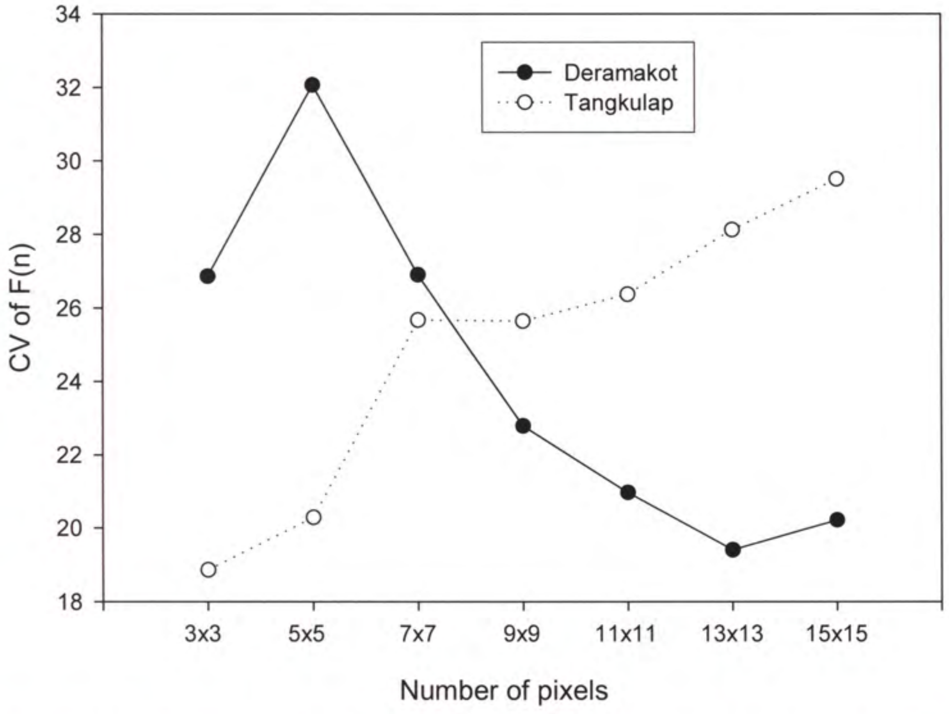

Figure 6. Coefficient of variations of F(n) with increasing unit area in Deramakot and Tangkulap.

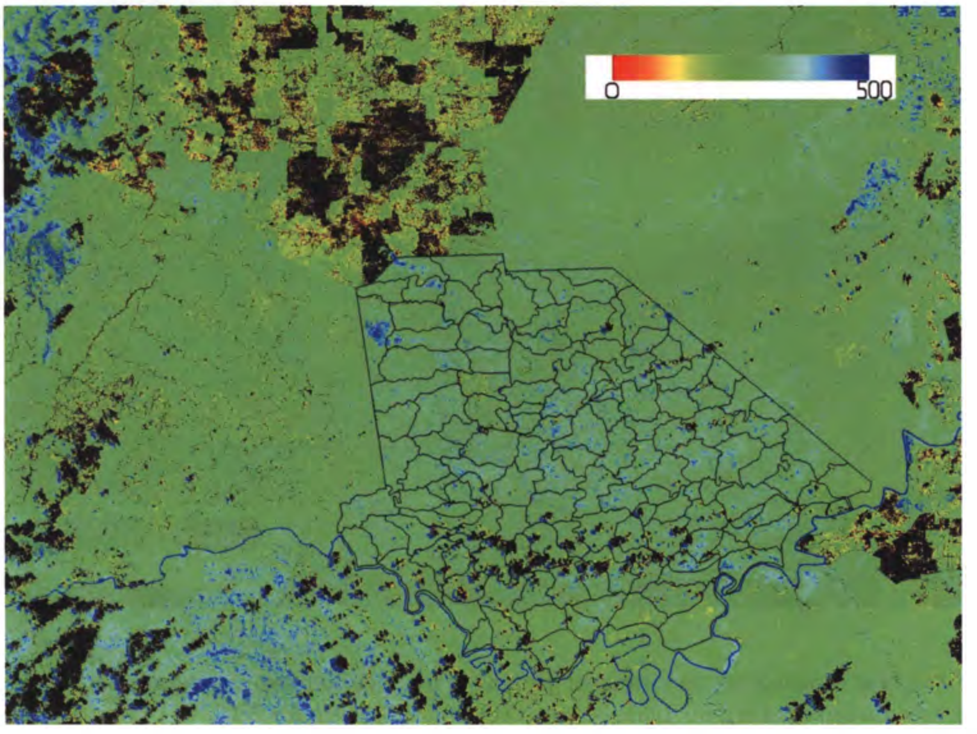

Figure 7. Map showing the spatial patterns of biomass densities (ton/ha) at the resolution of 30 x 30 m.

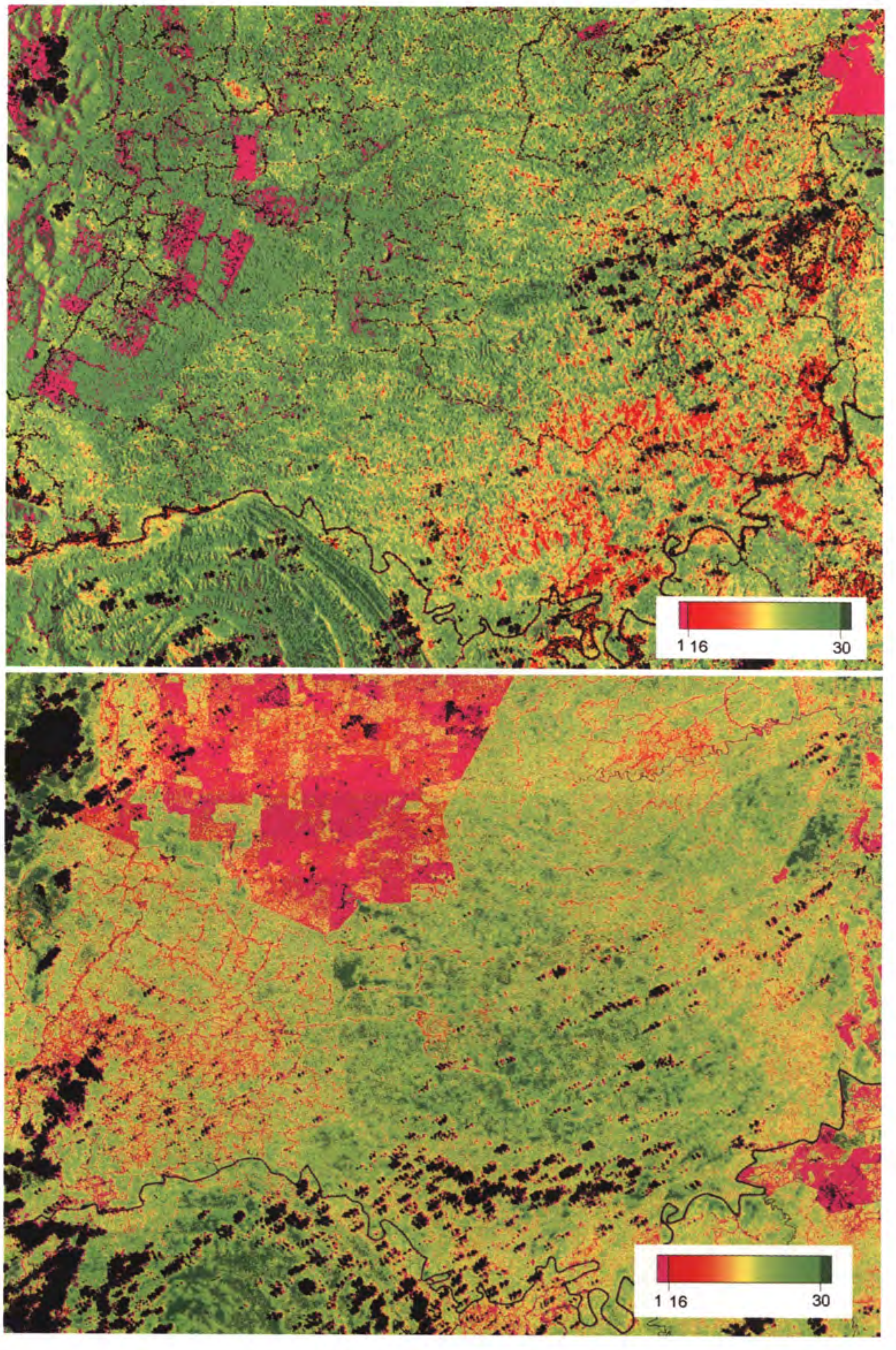

Figure 8. Map showing the reconstructed patterns of tree-family richness (number per 0.2 ha). Above, reconstructed pattern for 1985; below, reconstructed pattern for 2002.

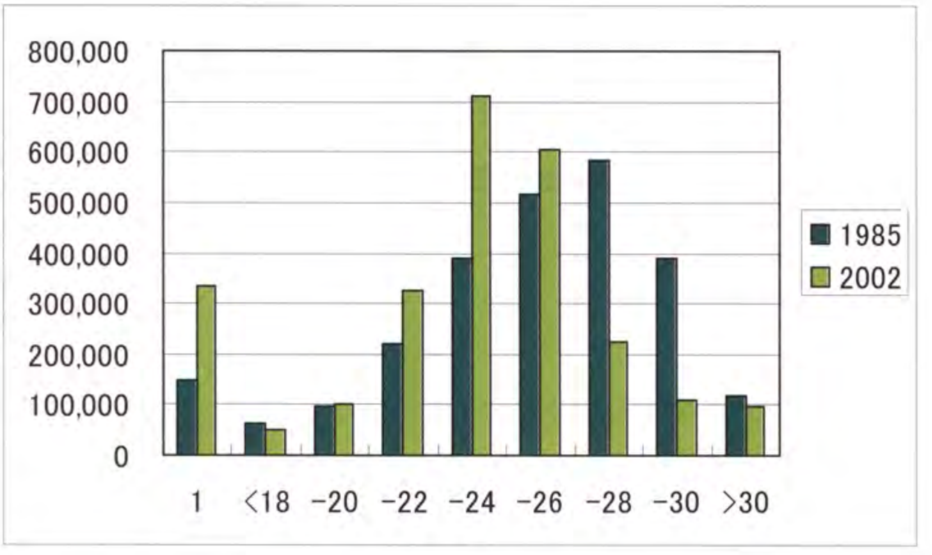

Figure 9. The number of pixels fallen in each tree-family richness class in the training area (the area shown in Fig. 7) for 1985 and 2002. Shifts due to land-use changes are shown.

Appendix 1. Estimated biomass density (ton/ha) and total biomass (ton) by compartment in Deramakot Forest Reserve. Biomass density was estimated according to two methods: (1) Pixels covered by clouds were removed, (2) Pixels covered by clouds were removed and further corrections were added according to Nakazono *et al.* (in prep.). Total biomass by compartment was estimated based on the method (2).

Compartment No.	Biomass density(ton/ha)(1)	Biomass density(ton/ha)(2)	Area of compartment (ha)	Total biomass (ton)
1	324	324	555.21	179918
2	333	327	496.93	162314
3	329	327	604.39	197725
4	327	327	309.03	100954
5	349	342	359.21	122689
6	357	351	567.06	199179
7	347	346	321.03	111017
8	336	336	329.19	110455
9	320	309	306.53	94670
10	338	338	467.51	157962
11	339	310	670.30	207625
12	358	356	774.28	275311
13	406	316	299.58	94681
14	350	327	607.39	198623
15	315	315	577.28	182097
16	342	333	402.06	133959
17	360	360	192.44	69200
18	352	346	552.30	190994
19	383	343	307.55	105513
20	355	355	547.22	194094
21	340	337	300.59	101295
22	350	349	383.90	133811
23	408	334	424.45	141707
24	329	324	336.52	108996
25	325	320	736.31	235480
26	387	355	450.62	160078
27	347	342	904.09	309283
28	347	347	368.86	127971
29	353	349	439.56	153338
30	387	346	474.34	163980
31	366	340	315.61	107203
32	354	354	168.14	59597
33	348	346	701.59	242503
34	292	286	431.54	123560
35	350	350	312.11	109234
35	384	345	328.48	113451
37	354	344	412.15	141612
38	412	371	93.37	34667
39	393	362	494.58	178915
40	363	361	766.95	276893
41	353	347	377.18	130930
42	448	411	96.58	39657
43	383	382	384.38	146644
44	326	304	432.93	131620
45	377	356	234.60	83541
46	362	362	254.73	92322
47	351	342	452.83	154763
48	345	345	117.83	40707
49	388	385	587.92	226418
50	413	341	497.28	169596
51	395	335	102.27	34215
52	378	354	488.40	172649
53	385	358	264.76	94815
54	381	361	175.77	63540
56	365	351	290.62	101906
57	341	339	704.14	238772

Compartment No.	Biomass density(ton/ha)(1)	Biomass density(ton/ha)(2)	Area of compartment (ha)	Total biomass (ton)
58	379	363	500.69	181723
59	405	357	392.36	140179
60	394	360	661.78	238132
61	357	348	338.96	118126
62	375	361	629.89	227322
63	374	367	328.44	120663
64	341	341	557.02	190032
65	396	360	414.53	149248
65	459	396	317.26	125678
66	390	361	516.87	186734
67	339	338	451.75	152560
68	384	383	503.29	192534
69	380	365	333.97	121846
70	359	343	503.67	172938
71	350	350	441.06	154216
72	362	347	498.29	172716
73	405	380	398.75	151695
74	371	353	584.56	206086
75	314	303	469.98	142264
76	371	359	500.07	179526
77	424	364	192.17	70046
78	348	347	151.21	52425
79	427	347	178.56	62013
80	409	362	231.45	83817
81	363	357	94.16	33634
82	371	310	266.03	82578
83	381	378	382.66	144536
84	364	342	548.81	187705
85	348	348	171.72	59727
86	354	354	581.59	205792
87	341	336	276.52	92894
88	343	341	315.77	107559
89	372	339	590.01	199782
90	381	353	413.94	145955
91	414	337	413.40	139238
92	463	364	163.01	59356
93	432	314	345.95	108580
94	438	343	133.03	45692
95	363	321	124.74	40083
96	350	316	343.12	108520
97	391	354	448.61	158682
98	397	326	354.82	115528
99	412	328	552.27	181380
100	433	356	466.99	166030
101	367	352	460.64	162300
102	447	325	340.56	110686
103	520	371	551.33	204603
104	424	315	319.27	100648
105	481	332	480.54	159568
106	358	356	362.44	129175
107	473	374	346.39	129465
108	399	338	206.39	69803
109	529	381	131.91	50311
110	724	480	360.64	173215
111	595	397	482.36	191427
112	396	317	370.01	117409
113	342	342	292.29	99932
113	597	422	218.33	92050
114	663	466	513.71	239455
115	458	336	449.81	151054
116	390	370	499.36	184856

Compartment No.	Biomass density(ton/ha)(1)	Biomass density(ton/ha)(2)	Area of compartment (ha)	Total biomass (ton)
117	461	360	638.06	229713
118	523	401	244.19	97959
119	441	339	539.00	182554
120	352	339	336.85	114234
121	508	361	354.36	127893
122	563	388	443.75	172138
123	500	358	477.28	170634
124	422	319	568.57	181557
125	310	303	873.66	264971
126	397	323	577.28	186292
127	366	326	374.64	122305
128	331	300	503.77	151325
129	352	339	334.56	113333
130	352	308	291.10	89753
131	325	287	454.33	130250
132	366	306	440.94	135070
134	353	285	674.21	192173
	Mean 388	Mean 347	Total 55148.77	Total 19038530

Floristic composition, stand structure, and above-ground biomass of the tropical rain forests of Deramakot and Tangkulap Forest Reserve in Malaysia under different forest managements

Running title: Floristic composition and stand structure of Deramakot Forest Reserve

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Abstract Floristic composition, stand structure, and above-ground biomass of tropical lowland rain forests were examined to compare the effects of different forest managements, i.e., old-growth forest as control, the forest harvested by the reduced-impact logging (RIL), and the forest harvested by the conventional method in Deramakot and Tangkulap Forest Reserve, Malaysian Borneo. Species diversity was rich in the old-growth forest and the forest harvested by RIL where climax and important commercial-timber species of Dipterocarpaceae dominated, while low in the forest harvested by the conventional method where pioneer species of the genus *Macaranga* (Euphorbiaceae) dominated. Size structure showed that Dipterocarp trees regenerated well in the old-growth forest and the forest harvested by RIL. On the other hand, Dipterocarp trees did not regenerate well in the forest harvested by the conventional method and Euphorbiaceae trees demonstrated an evidence of regeneration. Basal area and above-ground biomass in the old-growth forest and the forest harvested by RIL were higher than those of the forest harvested by the conventional method. Floristic composition, stand structure, and above-ground biomass were not different between the old-growth forest and the forest harvested by RIL. However, the species composition and above-ground biomass of the forest harvested by the conventional method were different from those of the old-growth forest and the forest harvested by RIL due to high impacts of logging. Thus, RIL management could keep species diversity, forest structure, and biomass at a pre-harvest status.

Abstract for policy-makers

We conducted a comparative study of the effects of different logging methods on the floristic composition, structure and biomass of tropical rain forests in Deramakot and Tangkulap Forest Reserve, Malaysian Borneo. Logging methods that we compared were the reduced-impact logging and the conventional logging. We also added an old-growth forest as control where the sign of logging was minimal in our comparison. Logging can leave impacts primarily though two pathways: instant mechanical influences by the reduction of biomass and structure versus long-term influences by modifying species composition. The results of our analyses demonstrated that the structure (for instance basal area, the sum of stem cross-sectional areas), above-ground biomass and species composition of the forest harvested by RIL were closer to the old-growth forest than to the forest harvested by the conventional method. Moreover,

RIL was effective in reducing both the instant mechanical and the long-term influences of logging. This indicated that RIL was certainly effective for achieving sustainable forest management.

Keywords above-ground biomass, Deramakot Forest Reserve, reduced-impact logging, Sabah, selective logging, species diversity, Tangkulap Forest Reserve.

Introduction

Timber exploitation since the mid 1970s has been altering the primary lowland forests of Sabah, Malaysian Borneo (Sabah Forestry Department 1989). To reduce the logging impacts for sustainable forest utilization, reduced-impact logging (RIL), a low impact logging technique of timber harvesting, was introduced in Sabah from 1996. It is believed that RIL is an adequate method for the sustainable management of tropical forests, because RIL can reduce the damages to the forests compared to the conventional logging method. However, there are relatively limited data to justify the sustainability of RIL in terms of full recovery of species composition, diversity and biomass after a timber harvest (Pinard and Putz 1996; Bertault and Sist 1997; Sist and Nguyen-The 2002; Bischoff *et al.* 2005).

Can the secondary succession of the tropical forests after a RIL eventually demonstrate a climax phase comparable to the pre-harvest status? To answer this question, we compared the recovery processes of logged-over forests subjected to RIL and to a conventional method (high impact logging) in terms of floristic composition, species diversity and biomass.

Methods

The study site

The study site (5°22'N, 117°25' E, approximately 300 m asl) is located in a lowland forest of the Deramakot Forest Reserve (DFR) and Tangkulap Forest Reserve (TFR) in Sabah, Malaysian Borneo. Forests in DFR and TFR had been selectively logged in the 1970s. The logging intensity varied from site to site. Subsequently, these forests were logged again with RIL from the 1990s in DFR and by a conventional method in TFR. Thus, the forests in DFR and TFR can be divided into the following three types as (1) old-growth forests in DFR without any logging records after the 1970s logging, (2) forests in DFR logged with RIL after 1996 in addition to the conventional logging prior to 1996, and (3) forests in TFR logged with the conventional method.

Field measurements and data analysis

Eleven research plots of 0.2 ha (100 m x 20 m, or 50 m x 40 m) were established in DFR and TFR under different forest managements (Table 1). In DFR, four plots were set up in the old-growth forest which was not logged since 1970s and four plots in the forests logged by RIL after 1996 in May 2003. In TFR, two plots in the forest logged by the conventional method in May 2003 and one plot was added in March 2005. All plots were divided into contiguous twenty 10 x 10 m subplots. The location and altitude of the plots were measured by using a portable receiver of global positioning system (Garmin GPS III plus, USA). All living trees larger than 10.0 cm in trunk diameter at breast height at 1.3 m (DBH) were measured first in May 2003 and re-measured in March 2005. Dead trees were checked at the tree census in March 2005. Buttressed or stilt-rooted trees were measured for trunk diameter at above the protrusions as "DBH" but not at 1.3m above the ground. Multiple trunks were separately recorded for DBH. To identify species, we collected leaves for voucher specimens from the tree crown using a clipper and a catapult. Species identification was based on the leaf specimens and bark characters. Voucher specimens were stored at the laboratory of the Deramakot Forestry Office in DFR. Species diversity of each plot was calculated with Fisher's diversity index (Fisher *et al.* 1943). The index is calculated as:

$$S = \alpha \ln (1+N/\alpha) \qquad (1)$$

where S is the number of species, N is the number of individuals, and α is a constant known as Fisher's diversity index. UPGMA cluster analysis was used for classification of the eleven plots on the basis of family composition in basal area. Leaf area index (LAI) was measured at five plots using LAI-2000 Canopy Analyzer (LI-COR, USA) in June 2003. The five plots were ET, C54, DMG, 63B, and TK1 (see Table 1 for the abbreviation of the plot). LAI was estimated based on the measurements at four corners of each of ten 10-m x 10-m subplots for each plot. This was repeated three times in different parts of the plot, from which the mean LAI was calculated for each plot. Above-ground biomass (AGB, t ha^{-1}) was estimated from the allometric function obtained by Brown (1997) as:

$$Wt = \exp(-2.134+2.530 \ln \mathrm{DBH}) \quad (2)$$

where Wt (kg) is the total weight of stem, branch and leaf. Change of AGB during tree censuses was calculated from the initial (May 2003) minus the final (March 2005) AGB.

Results

Species composition and diversity

The numbers of the observed families and species at the old growth and the RIL forests were higher than those of the forest harvested by the conventional method (analysis of variance, ANOVA, $F = 6.81$, $P < 0.05$ for observed family; $F = 7.14$, $P < 0.05$ for observed species; Figure 1). Species composition and diversity were not different between the old-growth forest and the forest harvested by RIL, but they were different between the forest harvested by RIL and the forest harvested by the conventional method (Figure 2, Table 2). Therefore, a most striking difference in species composition was found between the forest harvested by the conventional method and the rest (Figure 2). Further details of the observed species in the plots are listed in Appendix. The index of species richness of Fisher's α of the old growth forest and the forest harvested by RIL was higher than that of the forest harvested by the conventional method (ANOVA, $F = 13.1$, $P < 0.01$; Figure 1). The α of the old growth forest and the forest harvested by RIL was close to 100 while that of the forest harvested by the conventional method was approximately 20. The maximum value of α was 123.6 at the old growth forest at ETC and the minimum value was 18.7 at the forest harvested by the conventional method at TK3 (Table 3).

Stand structure and above-ground biomass

Stand structure was different between the forest harvested by RIL and the forest harvested by the conventional method (Figure 3). Stem density was not significantly different among the three categories of forest managements. However, maximum DBH and basal area were different between the forest harvested by RIL and the forest harvested by the conventional method (ANOVA, $F = 23.2$, $P < 0.001$ for maximum DBH; $F = 14.1$, $P < 0.01$ for basal area). DBH distribution in the forest harvested by RIL and the old growth forest showed an L-shaped pattern. DBH distribution of the forest harvested by the conventional method showed a lack of larger trees due to loggings (Figure 4). Dipterocarpaceae trees are of climax species in lowland forest, and this family is well-known as important commercial timer (Whitmore 1984). On the other hand, most of observed *Macaranga* (Euphorbiaceae) species were characterized as a gap-dependent species in regeneration (See details in Appendix, Slik *et al.* 2003). Their regeneration requires strong disturbance by large canopy opening with soil disturbance (Whitmore 1984). Thus, dominances of the Dipterocarpaceae and *Macaranga* can be used for forest condition as indicators for disturbance. According to the pattern of DBH distribution, Dipterocarpaceae trees were well regenerated both in the old growth forest and the forest harvested by RIL (Figure 5). On the other hand, Euphorbiaceae (the family of *Macaranga*) trees were well regenerated in the forest harvested by the conventional method (Figure 5). Old growth forest and the forest harvested by RIL were dominated by Dipterocarpaceae while the forest harvested by the conventional method was dominated by the genus *Macaranga* (Euphorbiaceae) (Figure 6).

Above-ground biomass (AGB) was also

different between the forest harvested by RIL and the forest harvested by the conventional method (ANOVA, $F = 21.4$, $P < 0.001$; Figure 3). AGB of old growth forest exceeded 500 t ha^{-1}. AGB of the forest harvested by RIL ranged from 455.4 to 322.7 t ha^{-1}. AGB of the forest harvested by the conventional method demonstrated a smallest value among the three forests (Figure 3). The old growth forest and the forest harvested by RIL showed a high gain and a low loss of AGB, while the forest harvested by the conventional method showed a low gain and a high loss of ABG. Thus, the net gain of AGB was high in the old growth forest and the forest harvested by RIL, and low in the forest harvested by the conventional method (Figure 7).

Discussion

Our results suggest that RIL is an efficient method to reduce logging impacts on species composition and diversity, and to keep AGB and minimize biomass loss compared with the conventional logging method. The size of canopy opening by loggings (i.e. creation of canopy gap) affected regeneration patterns and species composition elsewhere (Denslow, 1980; Pickett and White 1985). RIL operation regulates the amount of logged trees and their size (DBH), location, and transportation of harvested logs (Sabah Forestry Department and the Commission of the European Communities 2001). Consequently, RIL operation creates a smaller number of canopy gaps probably with a smaller mean size of canopy opening than the conventional logging (see Kitayama *et al.* in this volume). Shade-tolerant trees can regenerate under a darker light condition. Therefore, these trees could have been regenerated under small-sized canopy gaps in the forest harvested by RIL due to their physiological tolerance for reduced light. In contrast, the regeneration of shade-intolerant trees requires a sunnier condition (Turner 2001). Response to light condition associated with the difference in gap sizes caused a greater similarity of species composition and diversity between the old growth forest and the forest harvested by RIL, and facilitated the regeneration of dipterocarp trees in the forest harvested by RIL (Sist and Nguyen-The 2002; Bischoff *et al.* 2005).

Differences of forest managements were related to the differences in the disturbance regime and regeneration patterns. For example, bulldozers disturb topsoils by pulling out logged trees on the forest floor in the forest harvested by the conventional method (Pinard *et al.* 2000). From our study, the forest harvested by the conventional method was dominated by pioneer species such as the genus *Macaranga* of Euphorbiaceae. Euphorbiaceae trees are known to regenerate under large canopy gaps with disturbed soil conditions (Davies *et al.* 1998; Davies 2001). On the other hand, RIL operation is gentle to forest with minimum damage to soils (Sabah Forestry Department and the Commission of the European Communities 2001). Figure 8 shows an example of a RIL operation in Deramakot in 2004. The photograph indicates that the logged tree was extracted without damages to the surrounding trees. In contrast, an operation of the conventional method would have left a greater damage to the surrounding trees. Our analysis dealt with two to three decades of a secondary succession only, and whether the species composition and structure of the forest including shrubs and herbs (that we do not include in our current analysis) can fully recover to a pre-harvest condition is still not known. To confirm the sustainability of the biomass and floristic composition of tropical rain forests in DFR managed by RIL, long-term ecological monitoring is needed.

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Table 1. Description of the research plots. "RIL" indicates reduced-impact logging.

Plot name	(Abbreviation)	Plot size	Altitude (m)	Harvest methods
Old-growth unlogged since 1970's				
Ecological trail	(ECT)	100 m x 20 m	248	Primary forest
ET-antena	(ETA)	50 m x 40 m	248	Primary forest
ET-jauh	(ETJ)	50 m x 40 m	248	Unlogged since 1970's
C54	(C54)	50 m x 40 m	195	Unlogged since 1970's
RIL				
Mannan	(MAN)	100 m x 20 m	196	RIL 8 years after logging
Domingo	(DMG)	100 m x 20 m	200	RIL 8 years after logging
C63-bawah	(63B)	100 m x 20 m	195	RIL 3 years after logging
C63-atas	(63A)	100 m x 20 m	221	RIL 3 years after logging
Conventional method				
Tangkulap-1	(TK1)	100 m x 20 m	109	Conventional method
Tangkulap-2	(TK2)	50 m x 40 m	76	Conventional method
Tangkulap-3	(TK3)	100 m x 20 m	52	Conventional method

Table 2. Comparison of the floristic composition and diversity of the plots among different logging methods.

Plot	No. Family	No. Species	Fisher's α
Old-growth since 1970's			
ECT	27	66	123.6
ETA	20	48	75.9
ETJ	25	48	91.7
C54	20	42	102.2
RIL			
MAN	21	39	57.2
DMG	26	50	104.9
63B	29	62	83.4
63A	26	57	110.1
Conventional method			
TK1	13	27	23.1
TK2	18	27	36.1
TK3	18	32	18.7

Table 3. Comparison of the stand structure and above-ground biomass among different logging methods.

Plot	Density (0.2 ha^{-1})	Max DBH (cm)	Basal area (m^2 ha^{-1})	ABG (t ha^{-1})	LAI
Old-growth since 1970's					
ECT	151	106.4	39.3	521.7	6.37
ETA	144	129.1	40.6	482.4	–
ETJ	135	116.7	48.2	596.0	–
C54	102	102.9	38.5	483.0	5.70
RIL					
MAN	128	108.2	36.9	409.3	–
DMG	120	91.9	29.0	322.7	5.33
63B	154	113.7	38.0	455.4	4.57
63A	121	109.5	29.2	330.8	–
Conventional method					
TK1	126	61.4	21.9	203.4	4.99
TK2	84	72.5	25.5	265.3	–
TK3	85	55.3	11.3	96.2	–

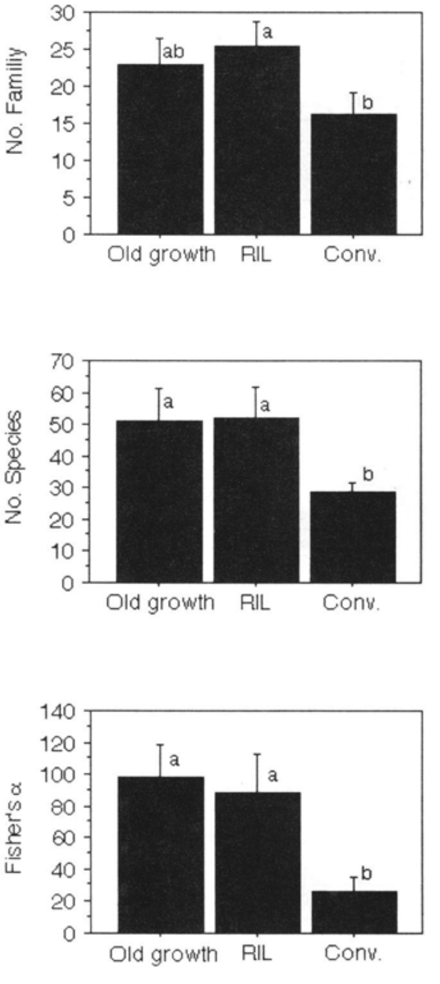

Figure 1. Differences of the number of families and species, and the diversity index of Fisher's α under different forest managements. Vertical bars show ± 1 SD. Means in a column followed by a different letter are significantly different according to the Bonferroni test at $P < 0.0167$. Old growth indicates the old growth forest without any logging records at least since 1970s, RIL indicates the forest logged by RIL after the 1970s, and Conv. indicates the forest logged persistently by the conventional method.

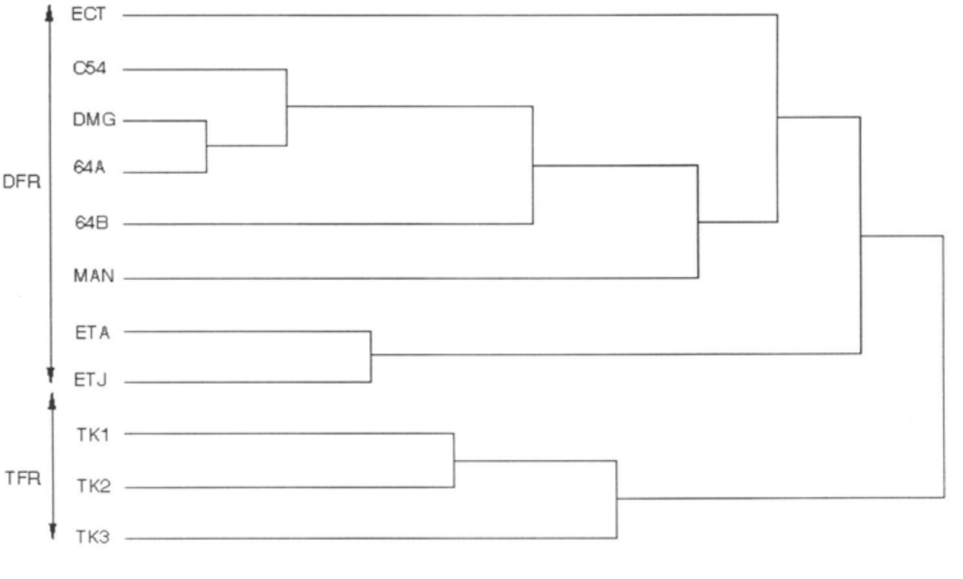

Figure 2. Dendrogram resulting from UPGMA cluster analyses to classify the eleven plots on the basis of family composition in basal area. The abbreviations in figure are the same as in Table 1.

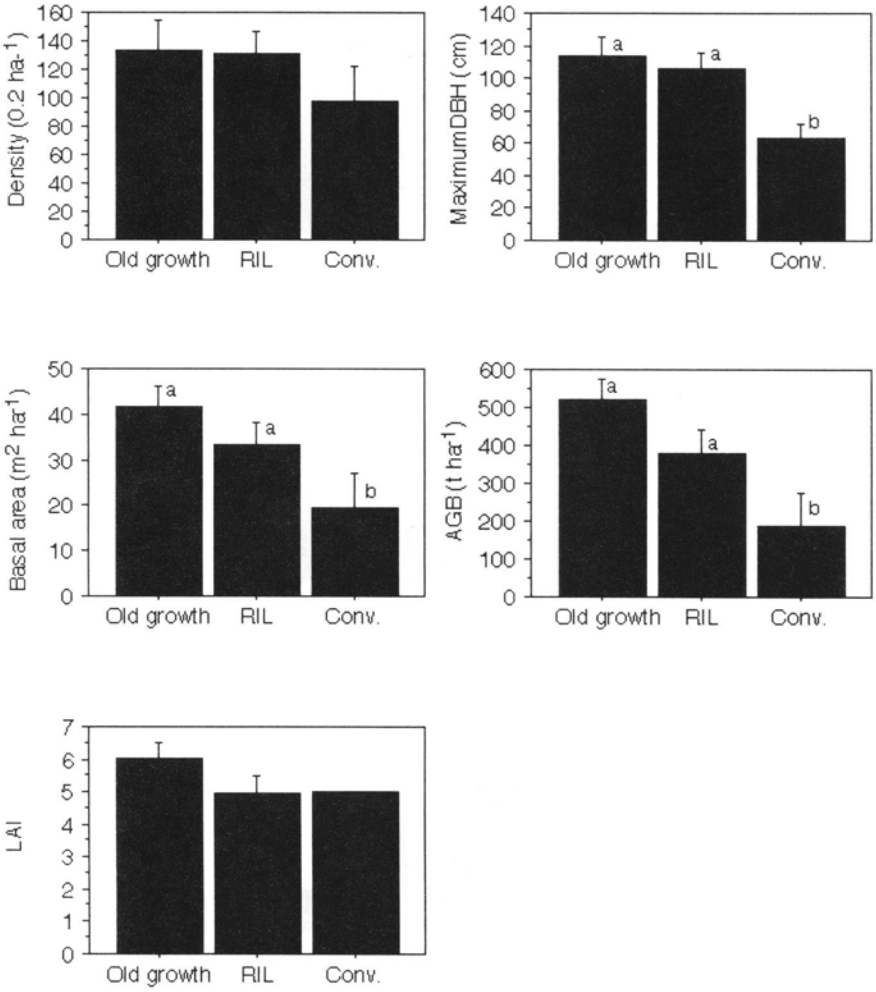

Figure 3. Differences of density, maximum DBH, basal area, AGB, and LAI among different forest managements. Vertical bars show ± 1 SD. Means in a column followed by a different letter are significantly different according to the Bonferroni test at $P < 0.0167$. The abbreviations of different forest managements in the figure are the same as in Figure 1.

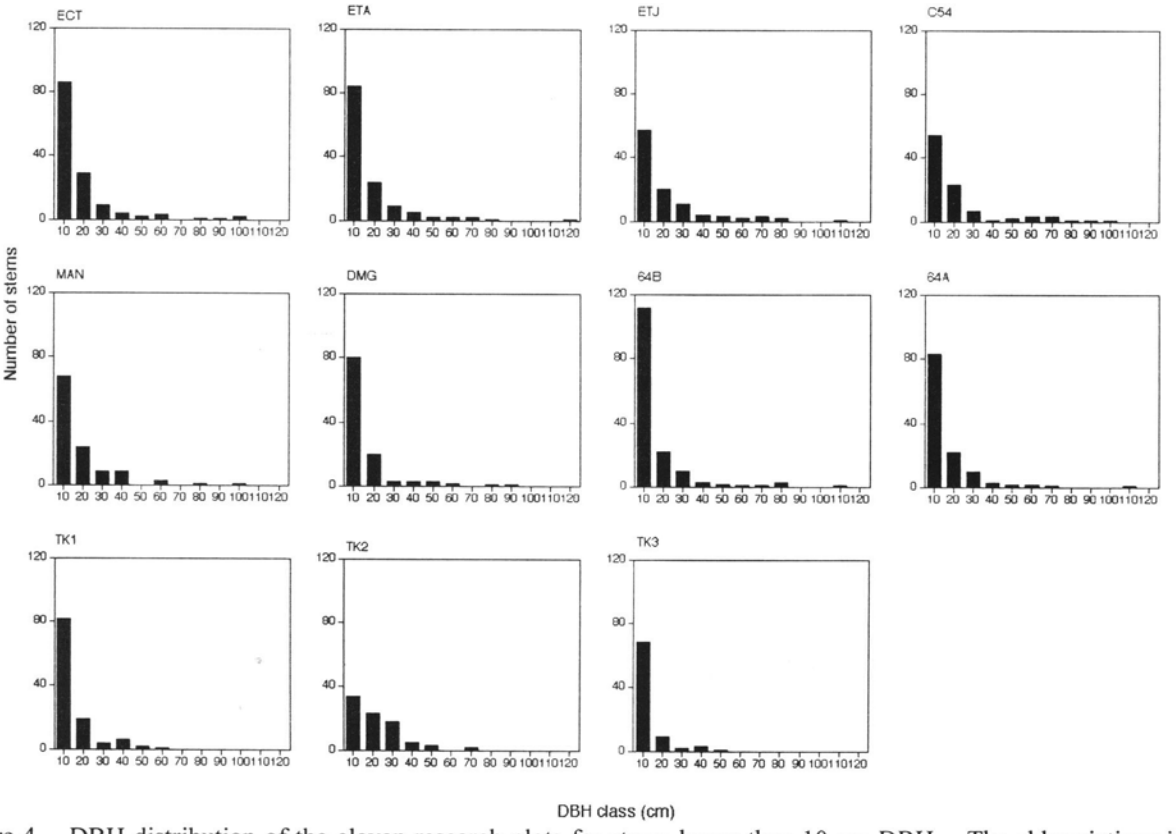

Figure 4. DBH distribution of the eleven research plots for stems larger than 10 cm DBH. The abbreviations in figure are the same as in Table 1.

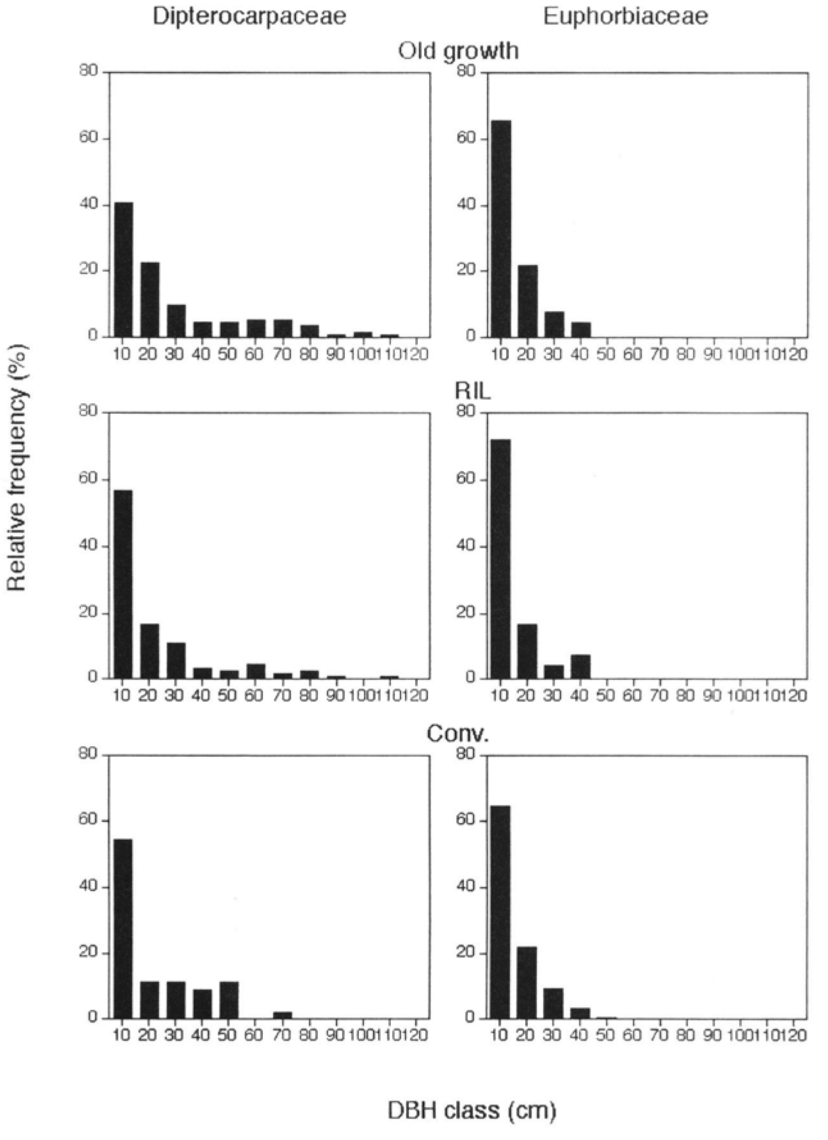

Figure 5. DBH distribution of Dipterocarpaceae and Euphorbiaceae by different forest management for stems larger than 10 cm DBH. The abbreviations of different forest managements in the figure are the same as in Figure 1.

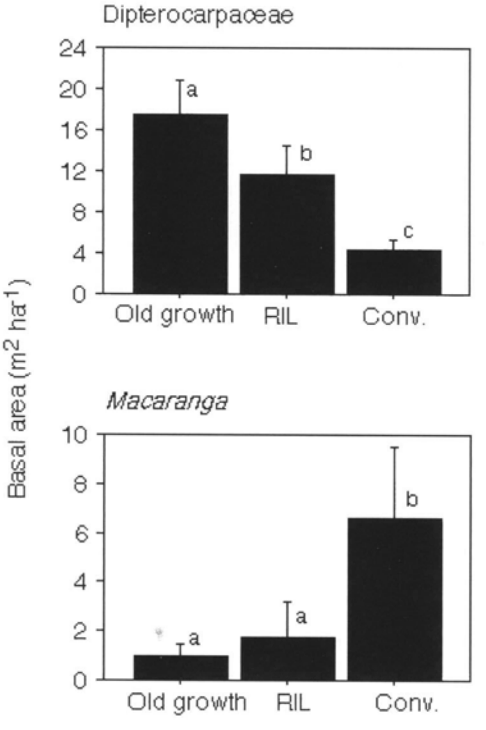

Figure 6. Basal area of Dipterocarpaceae and *Macaranga* of Euphorbiaceae by different logging methods. Vertical bars show ± 1 SD. Means in a column followed by a different letter are significantly different according to the Bonferroni test at $P < 0.0167$. The abbreviations of different forest managements in the figure are the same as in Figure 1.

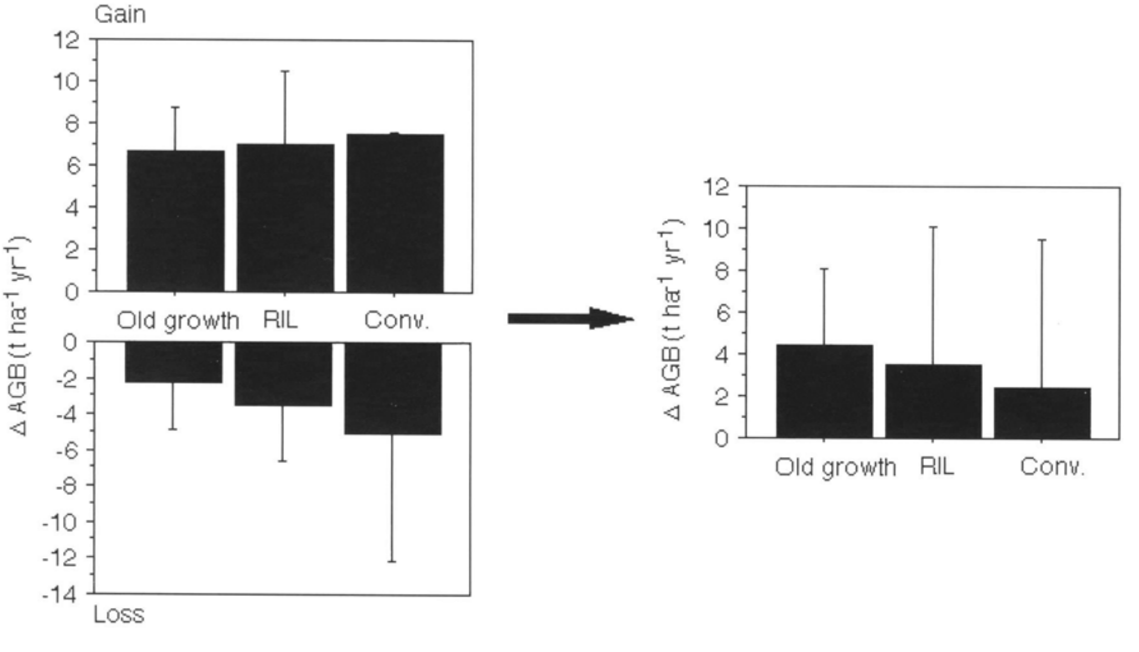

Figure 7. Changes of ABG by different forest management. Vertical bars show ± 1 SD. The abbreviations of different forest managements in the figure are the same as in Figure 1.

Figure 8. Example of a stump after logging by RIL. Note that logging operation was carried out without damage to the surrounding small trees.

Appendix 1. Species composition of the Ecological Trail (ECT) plot, showing the number of stems larger than 10cm DBH (N per 0.2ha), the relative basal area of stems larger than 10 cm DBH (RBA, %) and maximum DBH (Dmax, cm).

Family	Species	N	RBA	Dmax
Annonaceae	*Oncodostigma* sp.A	1	0.5	21.7
	Polyalthia sp.A	1	1.1	33.6
	Anno Indet sp.B	1	0.1	11.6
Apocynaceae	*Alstonia angustiloba*	1	0.9	29.2
Bombacaceae	*Durio acutifolius*	1	0.5	23.6
	Durio grandiflorus	1	0.1	10.9
	Neesia sp.A	1	0.1	10.2
Burseraceae	*Canarium hirtum*	2	1.0	31.2
	Canarium sp.A	2	4.4	65.4
	Dacryodes rostrata	2	0.4	15.1
Combretaceae	*Terminalia* sp.A	1	1.7	41.8
Dipterocarpaceae	*Dipterocarpus applanatus*	2	1.1	28.0
	Dipterocarpus stellatus	3	1.2	23.8
	Dryobalanops keithii	1	0.6	25.0
	Shorea fallax	2	7.0	64.6
	Shorea gibbosa	5	3.1	47.3
	Shorea macrophylla	2	7.3	85.9
	Shorea macroptera	9	5.1	46.3
	Shorea multiflora	1	0.1	13.3
	Shorea ovalis	1	0.4	18.7
	Shorea parvifolia	2	1.0	26.9
	Shorea parvistipulata	2	1.4	30.9
	Shorea pauciflora	2	11.3	106.4
	Shorea smithiana	1	0.1	13.0
	Vatica dulitensis	1	1.1	33.2
	Vatica sp.A	1	8.1	90.8
Ebenaceae	*Diospyros* sp.A	1	0.6	25.8
	Diospyros sp.B	1	0.6	24.4
	Diospyros sp.D	2	0.7	26.8
	Diospyros sp.E	1	0.2	15.4
Euphorbiaceae	*Baccaurea* sp.A	1	0.6	24.3
	Drypetes pendula	1	0.1	13.3
	Drypetes sp.B	1	0.2	14.0
	Drypetes sp.C	1	0.1	11.3
	Elateriospermum tapos	1	0.1	13.6
	Macaranga hypoleuca	1	1.4	37.1
	Mallotus penangensis	1	0.1	13.0
	Mallotus stipularis	2	0.4	15.1
Fagaceae	*Lithocarpus blumeanus*	1	0.9	29.4
	Lithocarpus sp.B	1	0.7	27.7
Flacourtiaceae	*Hydnocarpus* sp.A	2	0.6	20.9
	Ryparosa hulletii	1	0.2	17.3
Lauraceae	*Alseodaphne* sp.A	2	0.4	15.2
	Cryptocarya sp.B	1	0.1	13.7
	Dehaasia brachybotrys	1	0.1	10.5
	Endiandra sp.A	1	0.4	18.0
	Litsea sp.D	1	0.1	13.1
	Neolitsea sp.A	1	0.2	15.2
Lecythidaceae	*Barringtonia* sp.A	1	0.5	23.5
	Barringtonia sp.B	1	0.2	13.9
Leguminosae	*Crudia* sp.A	1	4.2	65.8
	Parkia sp.A	2	1.6	30.7
Melastomataceae	*Pternandra* sp.A	1	0.1	10.3
Meliaceae	*Aglaia shawiana*	1	0.1	10.8
	Aglaia sp.A	1	0.4	20.9
	Aglaia sp.D	1	0.1	11.7
	Aglaia sp.E	1	0.1	10.2
	Aglaia sp.G	1	0.1	13.8

	Aglaia sp.H	1	0.2	17.4
	Chisocheton sarawakanus	1	0.1	12.4
	Chisocheton sp.A	1	0.4	18.5
Moraceae	*Artocarpus odoratissimus*	1	0.2	17.5
	Artocarpus sp.A	1	0.1	12.3
Myristicaceae	*Gymnacranthera* sp.A	1	0.2	16.0
	Horsfieldia grandis	1	0.1	10.9
	Knema furfuracea	2	0.2	11.0
	Knema sp.B	1	1.0	32.0
Myrtaceae	*Syzygium* sp.A	3	1.5	27.0
	Syzygium sp.B	1	0.1	13.4
	Syzygium sp.D	2	0.6	21.8
Olacaceae	*Ochanostachys amentacea*	2	0.5	16.3
Oleaceae	*Chionanthus* sp.A	1	0.2	14.8
Rosaceae	*Prunus arborea*	1	2.6	52.1
Rubiaceae	*Porterandia* sp.A	1	0.2	15.3
Sapidaceae	*Lepisanthes* sp.A	1	0.1	11.6
	Nephelium lappaceum	1	0.2	14.9
	Nephelium uncinatum	2	0.7	21.1
	Pometia pinnata	1	1.9	43.2
Sapotaceae	*Madhuca kingiana*	1	0.1	12.0
	Madhuca malaccensis	2	0.2	12.3
	Palaquium sp.A	1	0.4	19.3
Sterculiaceae	*Heritiera elmerii*	1	0.4	18.5
	Heritiera simplicifolia	1	10.0	101.1
	Sterculia sp.A	1	0.4	18.5
Thymelaeaceae	*Gonystylus* sp.B	1	0.1	11.3
Tiliaceae	*Pentace borneensis*	2	0.2	12.7

Appendix 2. Species composition of the ET-Antena (ETA) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Annonaceae	*Cyathocalyx* sp.A	1	0.6	23.4
	Polyalthia sumatrana	2	0.4	14.5
	Popowia sp.A	1	0.3	14.2
Burseraceae	*Dacryodes* sp.A	2	0.3	12.6
	Dacryodes sp.B	1	0.1	12.2
	Dacryodes sp.D	1	0.1	10.2
Chrysobalanaceae	*Maranthes* sp.A	1	1.3	34.1
Compositae	*Vernonia arborea*	1	0.6	22.9
Ctennolophonaceae	*Ctenolophon parvifolius*	1	4.3	62.3
Dipterocarpaceae	*Dipterocarpus gracilis*	6	17.7	74.1
	Dipterocarpus sp.A	1	0.1	11.2
	Dryobalanops lanceolata	2	1.1	28.2
	Shorea domatiosa	2	5.1	66.0
	Shorea exelliptica	1	18.6	129.3
	Shorea macroptera	2	0.7	23.9
	Shorea multiflora	3	6.2	70.4
	Shorea parvifolia	4	3.0	31.9
	Shorea pauciflora	1	0.1	10.9
	Shorea smithiana	1	0.1	12.0
	Shorea sp.B	1	0.6	22.0
	Vatica oblongifolia	1	0.9	27.2
	Vatica sp.A	2	0.4	15.1
Ebenaceae	*Diospyros* sp.B	1	0.7	24.5
	Diospyros sp.C	1	0.1	11.6
Euphorbiaceae	*Aporusa* sp.C	1	0.4	18.5
	Botryophora sp.A	1	0.9	28.0
	Drypetes sp.B	1	0.1	11.8
	Euph Indet sp.A	2	0.4	13.6
	Macaranga conifera	3	3.1	44.3
	Macaranga hypoleuca	2	1.7	28.5
	Mallotus penangensis	7	1.4	20.4
	Mallotus wrayi	1	0.1	13.8

	Neoscortechinia forbesii	1	0.3	16.9
Fagaceae	*Lithocarpus bullatus*	1	2.7	49.7
	Quercus sp.A	1	2.1	44.1
Flacourtiaceae	*Ryparosa hulletii*	1	0.1	11.0
Lauraceae	*Cryptocarya* sp.C	1	0.3	15.7
	Litsea oppositifolia	1	0.1	12.9
	Litsea sp.A	1	0.4	19.7
	Litsea sp.B	1	0.1	10.1
	Litsea sp.D	1	0.6	23.6
	Litsea sp.G	1	0.1	10.0
Lecythidaceae	*Barringtonia* sp.B	1	0.1	11.3
Leguminosae	*Sindora irpicina*	1	1.1	31.6
Meliaceae	*Aglaia* sp.F	1	0.3	17.5
	Chisocheton sarawakanus	1	0.4	19.5
	Walsura pinnata	1	0.1	10.8
Myristicaceae	*Gymnacranthera* sp.A	1	0.1	12.4
	Knema sp.A	1	0.6	22.5
	Knema sp.B	5	1.7	27.3
	Knema sp.C	1	0.9	26.5
	Myristica sp.A	1	0.1	11.3
	Myristica sp.B	1	2.7	49.2
Myrtaceae	*Syzygium* sp.A	3	0.6	16.1
	Syzygium sp.B	1	0.1	13.7
	Syzygium sp.E	1	0.7	26.3
	Syzygium sp.J	1	1.1	32.8
	Syzygium sp.K	1	0.1	13.2
Olaceae	*Ochanostachys amentacea*	1	0.3	17.0
Polygalaceae	*Xanthophyllum affine*	6	1.0	14.9
	Xanthophyllum heterophyllum	1	0.1	11.8
Proteaceae	*Helicia* sp.A	1	1.3	33.0
Sapindaceae	*Nephelium* sp.B	1	0.6	22.2
Sapotaceae	*Palaquium* sp.A	1	0.1	12.1
	Payena microphylla	1	1.6	38.0
Simaraoubaceae	*Irvingia malayana*	2	2.7	36.3
Symplocaeae	*Symplocos* sp.A	1	0.3	16.6
Theaceae	*Pyrenaria* sp.A	1	0.1	12.2
Thymelaeaceae	*Gonystylus* sp.B	1	0.4	20.1
Tiliaceae	*Brownlowia peltata*	1	0.1	12.6
	Pentace borneensis	5	1.6	25.0
Indet	Indet sp.C	1	0.1	10.2

Appendix 3. Species composition of the ET-Jauh (ETJ) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Annonaceae	*Encosanthum* sp.A	2	0.2	11.6
	Polyalthia sumatrana	1	0.2	15.4
Bombacaceae	*Durio acutifolius*	2	0.2	12.7
	Durio oxyleanus	1	0.9	34.2
	Durio sp.C	1	0.4	23.0
	Neesia synandra	1	0.4	22.9
Burseraceae	*Dacryodes rostrata*	1	0.1	10.4
Celastraceae	*Lophopetalum beccarianum*	2	1.1	29.6
Chrysobalanaceae	*Kostermanthus* sp.A	1	1.0	35.8
	Kostermanthus sp.B	1	0.3	20.4
Cornaceae	*Mastixia cuspidata*	1	0.2	15.4
Dipterocarpaceae	*Dipterocarpus confertus*	1	10.9	116.7
	Parashorea malaanonan	1	0.1	12.4
	Parashorea tomentella	1	5.4	81.9
	Shorea domatiosa	5	18.2	84.9
	Shorea macroptera	1	0.7	30.1
	Shorea multiflora	4	2.7	51.8
	Shorea ovalis	1	4.0	70.4
	Shorea pauciflora	2	1.7	39.8
	Shorea pilosa	3	4.9	63.8

	Vatica dulitensis	1	0.2	14.6
	Vatica oblongifolia	1	0.4	23.4
	Vatica sp.A	4	4.9	50.2
Ebenaceae	*Diospyros elliptifolia*	1	0.3	18.2
	Diospyros sp.C	1	0.1	10.2
	Diospyros sp.F	1	0.1	10.8
Elaeocarpaceae	*Elaeocarpus* sp.A	1	0.5	24.7
Euphorbiaceae	*Aporusa* sp.A	1	0.2	15.8
	Baccaurea sp.A	6	2.7	23.2
	Baccaurea sp.B	2	3.0	45.3
	Baccaurea sp.D	1	0.1	10.1
	Drypetes pendula	1	0.2	16.2
	Drypetes sp.A	1	0.8	31.6
	Macaranga hypoleuca	3	1.9	29.6
	Macaranga pearsonii	1	1.0	35.8
	Mallotus penangensis	4	0.5	15.1
	Mallotus wrayi	1	0.1	11.1
	Neoscortechinia borneensis	1	0.4	21.8
	Neoscortechinia forbesii	1	0.3	18.0
Fagaceae	*Lithocarpus conocarpus*	1	0.3	19.3
	Lithocarpus sp.E	1	0.9	33.6
Flacourtiaceae	*Ryparosa* sp.A	2	1.4	33.8
Guttiferae	*Garcinia* sp.A	1	0.4	23.7
Lauraceae	*Alseodaphne* sp.A	2	1.2	36.4
	Beilschmiedia sp.A	1	2.1	51.7
Lecythidaceae	*Barringtonia* sp.A	1	0.9	34.1
	Barringtonia sp.B	2	0.5	18.0
Leguminosae	*Crudia* sp.A	1	0.2	16.3
	Cynometra sp.A	1	0.3	18.8
	Fordia sp.A	1	0.1	13.7
	Sindora irpicina	1	0.1	13.0
Melastomataceae	*Pternandra* sp.A	3	0.8	19.2
Meliaceae	*Aglaia shawiana*	1	0.1	10.2
	Aglaia sp.A	1	0.2	16.1
	Aglaia sp.H	1	0.2	16.3
Moraceae	*Artocarpus elasticus*	1	0.7	29.2
	Artocarpus tamaran	1	0.1	11.3
Myristicaceae	*Gymnacranthera* sp.A	2	0.2	11.8
	Horsfieldia grandis	1	0.2	15.4
	Knema sp.A	2	0.2	13.2
	Knema sp.D	2	0.2	12.4
	Myristica sp.B	3	2.6	42.1
	Myristica sp.C	2	0.9	31.2
Myrsinaceae	*Ardisia macrophylla*	1	0.1	10.1
Myrtaceae	*Syzygium* sp.A	2	1.1	35.0
	Syzygium sp.E	1	0.7	29.0
	Syzygium sp.G	1	0.2	17.8
Rubiaceae	*Porterandia* sp.A	1	0.3	18.4
	Rubiaceae Indet sp.A	1	7.3	95.7
Sapindaceae	*Nephelium ramboutan-ake*	1	0.3	18.9
Sapotaceae	*Madhuca kingiana*	1	0.3	18.0
	Madhuca sp.A	1	0.2	16.0
	Palaquium sp.B	1	0.2	17.3
Simaraoubaceae	*Eurycoma longifolia*	1	0.1	10.4
Sterculiaceae	*Scaphium macropodum*	1	0.6	27.8
Thymelaeaceae	*Gonystylus* sp.A	3	0.4	13.3
	Gonystylus sp.B	4	0.8	20.5
Tiliaceae	*Pentace borneensis*	3	0.6	18.4

Appendix 4. Species composition of the C54 (C54) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Annonaceae	*Oncodostigma* sp.A	1	0.7	24.6
	Polyalthia sp.A	1	0.4	18.9
Burseraceae	*Dacryodes* sp.A	2	0.4	16.8
Celastraceae	*Lophopetalum beccarianum*	4	2.8	36.6
Combretaceae	*Terminalia* sp.A	1	5.0	67.9
Dipterocarpaceae	*Dipterocarpus applanatus*	2	1.5	36.3
	Dipterocarpus caudiferus	1	0.4	18.1
	Dipterocarpus pachyphyllus	1	11.9	104.2
	Parashorea malaanonan	4	3.5	38.9
	Shorea almon	2	1.8	29.3
	Shorea fallax	1	4.7	65.9
	Shorea macroptera	1	0.8	27.9
	Shorea mecistopteryx	1	0.8	27.1
	Shorea parvifolia	2	5.6	68.7
	Shorea parvistipulata	1	1.0	29.7
	Shorea pauciflora	1	0.8	27.3
	Shorea pilosa	6	14.5	80.8
	Shorea smithiana	1	0.1	10.3
	Vatica sarawakensis	1	0.1	11.7
Ebenaceae	*Diospyros* sp.A	1	2.2	45.0
	Diospyros sp.C	1	0.3	14.0
	Diospyros sp.F	1	0.1	10.6
Euphorbiaceae	*Aporusa acuminatissima*	1	0.6	23.5
	Drypetes sp.A	1	0.3	17.0
	Glochidion sp.A	1	0.1	10.0
	Macaranga bancana	1	0.1	12.0
	Macaranga conifera	1	0.4	19.1
	Macaranga gigantea	1	0.8	28.1
	Macaranga hypoleuca	2	3.1	38.9
	Mallotus penangensis	1	0.1	10.4
	Mallotus stipularis	1	0.1	11.1
	Mallotus wrayi	3	0.4	12.5
Fagaceae	*Lithocarpus blumeanus*	1	6.4	76.3
Flacourtiaceae	*Hydnocarpus* sp.A	1	0.4	19.0
Guttiferae	*Garcinia* sp.B	1	0.3	15.6
	Garcinia sp.D	2	1.1	27.8
Lauraceae	*Dehaasia* sp.A	1	0.1	11.2
	Litsea sp.G	1	0.3	17.5
Lecythidaceae	*Barringtonia* sp.A	1	0.3	14.2
	Barringtonia sp.B	2	1.8	29.5
Leguminosae	*Koompassia excelsa*	1	0.3	17.8
	Parkia sp.A	2	1.0	22.1
Meliaceae	*Aglaia shawiana*	1	0.1	11.2
	Chisocheton sarawakanus	2	0.8	23.6
	Chisocheton sp.B	1	0.7	24.1
	Pysoxylon sp.A	1	0.1	11.0
Moraceae	*Artocarpus* sp.A	1	0.1	11.5
	Artocarpus sp.C	1	0.4	17.9
	Artocarpus sp.D	1	0.1	10.7
	Ficus sp.A	1	0.1	10.8
Myristicaceae	*Horsfieldia grandis*	1	0.1	10.0
	Knema sp.B	2	1.1	24.9
	Knema sp.D	1	0.1	13.3
	Myristica sp.A	1	0.6	23.6
Myrsinaceae	*Ardisia* sp.A	1	0.4	19.9
Myrtaceae	*Syzygium* sp.C	1	0.6	22.8
Olacaceae	*Ochanostachys amentacea*	1	3.1	53.5
Oleaceae	*Chionanthus* sp.A	1	0.7	25.7
Rhizphoraceae	*Anisophyllea borneensis*	1	0.1	10.0
Rubiaceae	*Pleiocarpidia* sp.A	2	0.3	13.2
Rutaceae	*Maclurodendron* sp.A	1	0.6	21.6

Sapindaceae	*Nephelium cuspidatum*	1	0.1	13.7
	Nephelium ramboutan-ake	1	0.3	15.4
Sapotaceae	Sapotaceae Indet sp. A	1	1.3	33.8
Sterculiaceae	*Heritiera simplicifolia*	1	5.9	73.2
	Scaphium macropodum	1	0.4	18.7
Thymelaceae	*Aquilaria malaccensis*	1	3.5	56.5
Tiliaceae	*Brownlowia peltata*	2	0.3	12.3
Indet	Indet sp.	1	0.1	10.9

Appendix 5. Species composition of the Mannan (MAN) plot. See Appendix 1 for abbreviations

Family	Species	N	RBA	Dmax
Annonaceae	*Encosanthum* sp.A	1	0.3	16.5
	Saigeraea sp.A	3	0.6	15.9
	Xylopia sp.A	1	0.3	14.1
Apocynaceae	*Alstonia angustiloba*	1	0.5	19.0
Bombacaceae	*Durio grandiflorus*	1	0.2	10.9
Burseraceae	*Dacryodes rostrata*	1	0.2	10.6
	Santiria sp.C	1	0.3	17.8
Compositae	*Vernonia arborea*	1	0.3	13.9
Dipterocarpaceae	*Dipterocarpus kerrii*	8	18.3	68.0
	Shorea almon	1	0.8	25.0
	Shorea domatiosa	2	1.1	24.8
	Shorea macroptera	3	2.6	38.5
	Shorea mecistopteryx	1	0.3	16.1
	Shorea pauciflora	2	0.5	16.9
	Shorea sp.A	2	2.3	31.9
	Vatica dulitensis	3	3.1	32.9
Ebenaceae	*Diospyros elliptifolia*	1	0.5	18.3
Elaeocarpaceae	*Elaeocarpus* sp.B	1	0.6	22.9
Euphorbiaceae	*Baccaurea* sp.D	1	0.8	25.0
	Drypetes sp.A	1	0.5	18.4
	Macaranga bancana	1	0.2	10.2
	Macaranga conifera	1	0.6	23.2
	Macaranga gigantea	4	7.8	43.9
	Macaranga hypoleuca	5	8.3	44.9
	Macaranga sp.A	2	0.3	11.5
	Macaranga winkleri	1	0.2	13.8
	Mallotus griffithii	3	0.5	11.7
	Mallotus wrayi	1	0.2	10.3
Fagaceae	*Lithocarpus blumeanus*	1	2.3	42.5
	Lithocarpus bullatus	1	0.3	16.4
	Lithocarpus conocarpus	1	0.5	18.3
Guttiferae	*Mesua micrantha*	1	0.2	11.4
Icacinaceae	*Stemonurus* sp.A	1	0.2	10.9
Lauraceae	*Alseodaphne* sp.A	1	14.7	107.7
	Beilschmiedia sp.B	1	0.2	13.0
	Litsea sp.B	1	0.2	12.9
	Litsea sp.E	1	0.2	10.0
Leguminosae	*Entada rheedii*	1	0.6	21.8
Magnoliaceae	*Magnolia* sp.A	1	0.8	25.1
	Magnolia sp.B	1	0.8	24.9
Melastomataceae	*Pternandra* sp.A	1	0.5	20.0
Meliaceae	*Dysoxylum* sp.A	1	0.2	10.0
Myristicaceae	*Gymnacranthera* sp.A	3	0.6	14.6
	Myristica sp.B	3	1.5	20.9
	Myristica sp.C	1	0.6	23.6
Myrtaceae	*Syzygium* sp.F	1	1.0	27.9
Olacaceae	*Ochanostachys amentacea*	1	1.0	28.3
Rubiaceae	*Anthocephalus chinensis*	1	2.6	45.1
	Pleiocarpidia sp.A	1	0.2	10.4
	Psydrax sp.A	1	0.2	12.5
	Rubiaceae Indet sp.A	1	9.7	87.5
	Rubiaceae Indet sp.B	1	5.7	66.9

Sapindaceae	*Pometia pinnata*	1	0.5	20.1
Sterculiaceae	*Scaphium longipetiolatum*	1	0.2	10.1
	Sterculia sp.C	1	0.2	11.7
Tiliaceae	*Microcos* sp.B	1	0.2	10.2
	Pentace borneensis	1	0.2	10.6
	Pentace laxiflora	3	2.1	30.2
Indet	Indet sp.C	1	0.2	11.3

Appendix 6. Species composition of the Domingo (DMG) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Annonaceae	*Polyalthia sumatrana*	1	0.4	16.4
	Annonaceae Indet sp.C	1	0.2	10.8
Bombacaceae	*Neesia synandra*	1	0.2	12.2
Burseraceae	*Canarium denticulatum*	1	0.4	17.4
	Dacryodes sp.B	1	3.7	49.2
	Dacryodes sp.D	1	0.2	11.2
	Santiria sp.B	1	0.8	22.9
Chrysobalanaceae	*Kostermanthus* sp.A	1	0.4	17.4
Combretaceae	*Terminalia* sp.A	1	0.4	16.5
Compositae	*Vernonia arborea*	1	1.4	29.8
Dipterocarpaceae	*Dipterocarpus confertus*	1	5.2	58.9
	Dipterocarpus humeratus	1	2.9	44.1
	Dipterocarpus kerrii	4	1.0	16.6
	Dipterocarpus sp.B	1	0.2	13.0
	Hopea beccariana	1	0.2	12.5
	Hopea nervosa	1	0.2	12.2
	Parashorea malaanonan	1	0.4	14.6
	Shorea beccariana	1	11.2	86.3
	Shorea gibbosa	3	1.2	18.9
	Shorea leprosula	1	1.4	30.8
	Shorea macroptera	5	14.9	68.8
	Shorea mecistopteryx	1	0.4	14.1
	Shorea parvistipulata	2	1.6	28.4
	Shorea pilosa	1	12.8	91.9
	Shorea sp.B	1	0.2	13.5
Ebenaceae	*Diospyros* sp.A	2	0.4	11.1
Euphorbiaceae	*Aporusa acuminatissima*	1	0.2	12.2
	Aporusa sp.A	1	0.2	11.8
	Aporusa sp.E	1	0.2	10.1
	Cleistanthus sp.B	1	0.2	13.3
	Drypetes pendula	2	1.4	22.9
	Macaranga conifera	2	1.0	18.3
	Macaranga pearsonii	1	1.7	33.6
	Mallotus penangensis	9	2.7	16.6
Fagaceae	*Castanopsis* sp.A	2	1.4	26.2
	Lithocarpus sp.D	1	0.4	14.9
Flacourtiaceae	*Casearia* sp.A	1	0.4	16.2
	Hydnocarpus sp.B	1	0.2	10.1
	Ryparosa sp.A	1	0.6	20.3
Guttiferae	*Garcinia* sp.A	1	0.2	12.6
	Garcinia sp.B	1	0.2	11.3
	Garcinia sp.C	1	0.2	12.5
Icacinaceae	*Stemonurus* sp.A	1	0.2	11.6
Lauraceae	*Beilschmiedia* sp.B	1	3.1	44.9
	Dehaasia brachybotrys	1	0.6	18.4
	Litsea sp.C	1	0.2	11.5
Lecythidaceae	*Barringtonia* sp.A	1	0.4	14.8
	Barringtonia sp.B	1	0.2	11.7
Leguminosae	*Cynometra* sp.A	1	0.4	14.6
	Dialium sp.A	1	0.2	13.1
Melastomataceae	*Pternandra* sp.A	1	1.2	26.9
Meliaceae	*Aglaia* sp.B	1	0.2	10.4
	Chisocheton sarawakanus	1	0.2	12.8

Myristicaceae	*Knema* sp.A	1	0.4	15.1
	Myristica sp.C	1	0.6	20.6
Myrtaceae	*Syzygium* sp.A	1	1.7	33.2
	Syzygium sp.F	1	5.4	59.2
	Syzygium sp.I	1	0.2	10.3
Rhizphoraceae	*Carallia brachiata*	1	0.2	11.8
Sapindaceae	*Dimocarpus* sp.A	1	1.2	28.2
	Nephelium ramboutan-ake	1	0.2	10.7
	Nephelium sp.A	1	0.2	11.7
Sapotaceae	*Madhuca malaccensis*	5	2.5	24.3
	Palaquium sp.A	1	0.4	16.8
Sterculiaceae	*Scaphium longipetiolatum*	1	1.2	27.5
	Scaphium macropodum	1	0.6	19.2
Symplocaceae	*Symplocos fasciculata*	1	0.4	14.9
Tiliaceae	*Pentace laxiflora*	7	3.1	25.9
Trigoniaceae	*Trigoniastrum hypoleucum*	2	1.6	23.2
Verbenaceae	*Teijsmanniodendron holophyllum*	1	0.4	15.9

Appendix 7. Species composition of the C63-Bawah (63B) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Annonaceae	*Polyalthia* sp.A	1	0.1	10.3
	Polyalthia sumatrana	2	0.4	17.7
Bombacaceae	*Durio acutifolius*	1	0.4	19.8
Burseraceae	*Canarium denticulatum*	1	0.1	11.8
	Canarium sp.A	1	0.1	11.1
	Dacryodes sp.B	1	3.6	59.5
Celastraceae	*Lophopetalum beccarianum*	1	0.1	10.3
Chrysobalanaceae	*Licania splendens*	1	0.1	10.8
Crpteroniaceae	*Crypteronia griffithii*	1	0.1	10.6
Dipterocarpaceae	*Anisoptera gradistipula*	1	2.1	44.8
	Dipterocarpus acutangulus	1	0.3	14.8
	Dipterocarpus caudiferus	2	0.3	12.1
	Dipterocarpus confertus	1	7.7	86.7
	Dipterocarpus kerrii	2	0.9	27.3
	Parashorea malaanonan	3	1.8	34.0
	Shorea beccariana	1	1.8	41.8
	Shorea domatiosa	1	0.3	13.9
	Shorea exelliptica	1	0.8	27.7
	Shorea fallax	4	9.9	88.4
	Shorea gibbosa	1	0.5	23.4
	Shorea macroptera	7	5.9	70.7
	Shorea multiflora	3	0.8	20.8
	Shorea ovalis	1	1.6	38.8
	Shorea parvifolia	6	2.1	22.8
	Shorea parvistipulata	1	0.1	10.1
	Shorea smithiana	1	0.5	23.5
	Vatica sp.A	1	0.4	20.0
Ebenaceae	*Diospyros* sp.A	1	0.5	21.3
	Diospyros sp.C	1	0.1	10.3
Euphorbiaceae	*Aporusa grandistipulata*	3	0.8	20.2
	Baccaurea sp.A	1	0.1	12.2
	Baccaurea sp.B	1	1.6	39.3
	Baccaurea sp.D	2	0.7	20.5
	Chaetocarpus castanocarpus	1	0.9	30.5
	Drypetes pendula	1	0.4	19.2
	Glochidion sp.A	3	0.7	18.3
	Glochidion sp.B	4	1.3	22.3
	Macaranga bancana	1	0.1	12.3
	Macaranga conifera	2	0.7	22.4
	Macaranga gigantea	4	1.0	18.6
	Macaranga hypoleuca	10	2.6	20.2
	Macaranga pearsonii	1	0.4	20.5
	Mallotus penangensis	2	0.5	16.6

	Mallotus wrayi	1	0.1	10.5
Fagaceae	*Lithocarpus conocarpus*	2	0.5	15.7
	Lithocarpus sp.A	1	0.7	24.3
	Lithocarpus sp.C	1	0.1	12.4
Flacourtiaceae	*Hydnocarpus* sp.A	1	1.0	32.2
	Hydnocarpus sp.C	1	0.3	14.1
Guttiferae	*Calophyllum* sp.A	1	1.0	31.9
	Garcinia sp.D	1	0.3	14.3
Icacinaceae	*Stemonurus* sp.A	1	0.1	12.8
Lauraceae	*Alseodaphne* sp.A	1	0.1	10.8
	Litsea sp.C	1	0.1	11.1
	Litsea sp.D	1	2.1	44.6
	Litsea sp.F	1	0.4	20.5
	Nothaphoebe sp.A	1	3.8	60.3
Magnoliaceae	*Magnolia* sp.A	1	0.3	15.5
	Magnolia sp.B	1	0.3	14.3
Melastmotaceae	*Pternandra* sp.A	2	0.3	12.0
Meliaceae	*Chisocheton sarawakanus*	1	0.1	12.8
Moraceae	*Artocarpus* sp.A	1	0.1	13.8
	Ficus sp.B	1	3.3	56.0
Myristicaceae	*Knema* sp.A	2	0.3	12.4
	Knema sp.B	1	0.3	15.0
	Knema sp.C	1	0.1	13.8
	Myristica sp.	1	0.1	12.0
Myrtaceae	*Syzygium* sp.H	1	0.1	13.5
	Syzygium sp.L	1	0.1	10.4
Rubiaceae	*Pleiocarpidia* sp.A	2	1.6	32.7
	Rubi Indet sp.A	4	14.2	113.9
Rutaceae	*Melicope* sp.A	1	0.3	15.7
Sapindaceae	*Dimocarpus* sp.A	1	0.4	18.7
	Nephelium uncinatum	1	0.1	13.6
Sapotaceae	*Madhuca kingiana*	2	0.4	15.5
	Palaquium sp.A	1	0.1	12.0
	Palaquium sp.B	1	0.4	18.6
	Payena microphylla	1	0.3	15.0
Sterculiaceae	*Pterocymbium* sp.A	1	1.0	32.2
	Scaphium macropodum	1	7.6	86.0
	Sterculia sp.B	1	0.1	11.3
Theaceae	*Adinandra myroneura*	3	0.9	16.8
Tiliaceae	*Microcos* sp.A	1	0.8	26.9
	Microcos sp.B	1	0.4	18.2
	Pentace borneensis	1	0.1	11.0
Trigoniaceae	*Trigoniastrum hypoleucum*	1	0.1	11.1

Appendix 8. Species composition of the C63-Atas (63A) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Annonaceae	*Xylopia* sp.A	1	0.5	19.6
Bombacaceae	*Durio* sp.B	2	0.7	15.6
	Neesia synandra	1	0.3	16.6
Burseraceae	*Dacryodes* sp.D	1	0.3	15.2
	Santiria sp.A	1	0.3	16.6
Celastraceae	*Lophopetalum beccarianum*	2	0.7	17.1
	Lophopetalum sp.A	5	5.9	46.8
Chrysobalanaceae	*Kostermanthus* sp.A	1	2.1	40.2
Dipterocarpaceae	*Dipterocarpus caudiferus*	1	0.3	17.5
	Dipterocarpus gracilis	1	3.8	54.7
	Dipterocarpus humeratus	1	6.3	69.3
	Dipterocarpus kerrii	1	0.2	11.2
	Dipterocarpus stellatus	1	0.2	11.9
	Dryobalanops lanceolata	1	0.2	12.3
	Parashorea malaanonan	2	2.6	36.8
	Shorea almon	1	0.2	12.6
	Shorea domatiosa	3	16.0	110.1
	Shorea fallax	1	1.0	26.7

	Shorea gibbosa	2	2.1	38.0
	Shorea leprosula	1	4.1	56.7
	Shorea macroptera	3	0.7	16.0
	Shorea mecistopteryx	6	2.5	22.1
	Shorea ovalis	2	6.4	63.0
	Shorea parvifolia	1	0.7	22.8
	Shorea pauciflora	6	8.6	77.5
	Shorea pilosa	1	1.5	33.5
	Shorea smithiana	1	0.2	13.8
	Vatica dulitensis	5	1.6	20.3
	Vatica sp.A	1	0.2	13.4
Ebenaceae	*Diospyros elliptifolia*	1	1.2	29.0
	Diospyros sp.E	1	0.2	10.5
	Diospyros sp.H	1	0.3	17.4
Euphorbiaceae	*Aporusa acuminatissima*	2	0.5	13.8
	Aporusa sp.D	1	0.2	10.1
	Baccaurea sp.A	1	0.2	11.2
	Baccaurea sp.B	1	0.2	11.6
	Drypetes pendula	1	0.5	19.8
	Macaranga conifera	1	2.1	41.2
	Mallotus penangensis	1	0.5	18.0
	Mallotus stipularis	1	0.5	20.1
	Mallotus wrayi	1	0.2	12.5
Fagaceae	*Castanopsis* sp.A	1	0.8	25.5
	Lithocarpus conocarpus	1	0.2	12.6
Flacourtiaceae	*Hydnocarpus* sp.A	3	2.1	31.4
Guttiferae	*Garcinia* sp.B	2	0.5	12.3
	Garcinia sp.D	1	0.5	20.8
Icacinaceae	*Stemonurus* sp.A	1	0.3	15.3
Lauraceae	*Alseodaphne* sp.B	1	0.5	20.6
	Cryptocarya sp.A	2	0.8	22.9
	Litsea sp.A	1	0.2	11.7
	Litsea sp.C	3	1.0	21.1
	Litsea sp.D	1	1.3	32.8
Lecythidaceae	*Barringtonia* sp.B	1	0.3	15.5
Leguminosae	*Archidendron* sp.A	1	0.5	20.4
	Fordia splendidussima	1	0.2	10.6
	Ormosia sp.A	1	0.2	11.3
Melastomataceae	*Pternandra* sp.A	1	0.5	18.1
Meliaceae	*Reinwardtiodendron* sp.A	1	0.2	10.4
	Walsura pinnata	1	0.2	12.2
	Walsura sp.A	1	1.0	26.8
Moraceae	*Artocarpus odoratissimus*	1	1.3	31.3
	Parartocarpus sp.A	1	0.8	26.4
Myristicaceae	*Gymnacranthera* sp.A	2	0.7	17.7
	Knema sp.A	1	0.3	14.0
	Knema sp.B	1	0.2	13.4
	Myristica sp.C	2	0.3	10.5
Myrtaceae	*Syzygium* sp.A	1	0.2	12.2
Olacaceae	*Ochanostachys amentacea*	2	2.5	36.4
Rhizphoraceae	*Carallia brachiata*	1	0.2	12.8
Rubiaceae	*Rothmannia* sp.A	1	0.3	17.2
Sapindaceae	*Dimocarpus* sp.A	1	0.7	21.3
	Pometia pinnata	1	0.2	11.6
Sapotaceae	*Palaquium* sp.A	1	0.2	12.4
	Palaquium sp.C	1	0.3	13.9
	Palaquium sp.D	1	0.5	19.7
	Payena microphylla	1	0.3	15.3
Sterculiaceae	*Sterculia* sp.B	1	1.6	35.7
	Sterculia sp.C	1	1.0	27.5
Tiliaceae	*Pentace laxiflora*	1	0.3	17.6
	Pentace sp.A	2	0.3	10.8
Verbenaceae	*Teijsmanniodendron holophyllum*	1	0.3	15.5

Appendix 9. Species composition of the Tangkulap-1 (TK1) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Bombacaceae	*Durio* sp.A	1	0.2	12.9
Burseraceae	*Dacryodes* sp.D	1	0.2	10.7
Dipterocarpaceae	*Dipterocarpus caudiferus*	1	0.2	12.2
	Dipterocarpus pachyphyllus	1	6.0	56.6
	Dryobalanops beccarii	3	1.9	25.0
	Dryobalanops lanceolata	2	9.9	58.6
	Parashorea tomentella	3	1.2	16.8
	Shorea acuminatissima	1	0.5	16.4
	Shorea domatiosa	1	0.2	11.7
	Shorea gibbosa	3	3.6	36.8
	Shorea parvistipulata	1	1.0	23.7
Ebenaceae	*Diospyros* sp.I	1	0.2	10.3
Euphorbiaceae	*Aporusa* sp.B	2	0.5	13.6
	Glochidion sp.B	1	0.5	17.0
	Macaranga conifera	2	5.0	43.8
	Macaranga gigantea	2	0.5	13.5
	Macaranga hypoleuca	8	16.1	42.9
	Macaranga pearsonii	52	26.7	31.1
	Phychopyxis sp.A	1	1.4	26.6
Flacourtiaceae	*Hydnocarpus* sp.A	2	0.7	13.3
	Hydnocarpus sp.B	2	0.7	17.3
Lauraceae	*Eusideroxylon zwageri*	1	7.2	61.5
	Laur Indet sp.A	1	0.5	17.1
Leguminosae	*Archidendron* sp.A	1	0.2	12.7
	Fordia splendidussima	2	1.0	18.8
	Sindora irpicina	1	0.2	11.4
Magnoliaceae	*Magnolia* sp.B	1	0.2	10.4
Melastomataceae	*Pternandra* sp.A	1	0.2	10.3
Moraceae	*Artocarpus* sp.B	2	0.7	16.4
Myristicaceae	*Knema* sp.D	2	1.0	18.1
Myrtaceae	*Syzygium* sp.A	1	3.4	42.2
Rhamnaceae	*Alphitonia excelsa*	1	1.4	27.0
Sapindaceae	*Guioa* sp.A	1	0.2	11.4
Sapotaceae	*Madhuca* sp.A	1	1.7	29.1
	Palaquium sericeum	1	0.2	11.4
	Palaquium sp.A	1	3.1	40.8
Sterculiaceae	*Sterculia* sp.B	1	0.2	10.1
Verbenaceae	*Teijsmanniodendron holophyllum*	1	0.7	20.4
Indet	Indet sp.B	1	0.2	11.1

Appendix 10. Species composition of the Tangkulap-2 (TK2) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Annonaceae	Anno Indet sp.A	1	0.2	12.4
Bombacaceae	*Durio acutifolius*	1	0.4	14.6
	Neesia synandra	1	0.6	20.8
Burseraceae	*Dacryodes* sp.A	1	0.4	15.7
	Dacryodes sp.B	1	1.5	31.8
Combretaceae	*Terminalia* sp.A	1	0.2	12.8
Dipterocarpaceae	*Dipterocarpus pachyphyllus*	1	1.5	31.4
	Dryobalanops beccarii	2	2.8	42.3
	Parashorea malaanonan	2	0.4	10.2
	Parashorea tomentella	1	4.2	53.7
	Shorea beccariana	2	0.7	18.0
	Shorea exelliptica	1	7.9	73.9
	Shorea macroptera	2	1.5	30.8
	Shorea ovalis	1	4.4	54.9
	Shorea sp.A	2	2.0	31.2
Ebenaceae	*Diospyros elliptifolia*	1	0.9	26.2
	Diospyros sp.G	1	0.2	10.4
Euphorbiaceae	*Aporusa acuminatissima*	1	0.2	12.1

	Croton argyratus	1	0.2	10.3
	Macaranga conifera	10	16.2	52.8
	Macaranga gigantea	4	7.7	42.4
	Macaranga hypoleuca	1	0.6	18.2
	Macaranga pearsonii	16	18.4	42.6
Fagaceae	*Lithocarpus conocarpus*	1	1.8	35.7
Flacourtiaceae	*Hydnocarpus* sp.	3	1.3	20.5
	Hydnocarpus sp.A	3	4.2	40.5
Lauraceae	*Eusideroxylon zwageri*	1	0.6	19.1
Leguminosae	*Peltophorum racemosum*	4	0.9	13.5
Melastomataceae	*Pternandra* sp.A	2	1.5	27.2
Meliaceae	*Aglaia* sp.A	1	0.2	10.9
Myristicaceae	*Knema* sp.A	1	0.2	13.0
	Myristica sp.C	1	0.9	26.0
Olacaceae	*Ochanostachys amentacea*	1	0.2	10.3
Polygalaceae	*Xanthophyllum* sp.A	1	0.2	11.6
Rubiaceae	*Timonius villamilii*	1	0.6	21.1
Sapindaceae	*Dimocarpus* sp.A	1	1.3	30.1
Sapotaceae	*Madhuca malaccensis*	1	0.7	22.4
	Palaquium beccarianum	1	0.9	25.3
	Payena microphylla	1	7.2	70.8
Sterculiaceae	*Sterculia cordata*	1	1.5	32.0
	Sterculia sp.B	1	0.4	17.0
Thymelaceae	*Gonystylus* sp.A	1	0.2	10.2
Tiliaceae	*Pentace laxiflora*	1	2.6	42.9

Appendix 11. Species composition of the Tangkulap-3 (TK3) plot. See Appendix 1 for abbreviations.

Family	Species	N	RBA	Dmax
Bombacaceae	*Durio* sp.C	1	0.9	16.9
Dilleniaceae	*Dillenia* sp. A	1	1.8	23.0
Dipterocarpaceae	*Dipterocarpus gracilis*	1	0.4	10.2
	Parashorea malaanonan	2	8.1	45.1
	Parashorea tomentella	3	2.2	21.1
	Shorea almon	2	1.3	15.1
	Shorea exelliptica	1	7.6	46.3
	Shorea pauciflora	3	15.7	55.3
	Vatica oblongifolia	2	3.1	23.8
Euphorbiaceae	*Macaranga conifera*	4	3.6	22.9
	Macaranga gigantea	7	7.6	32.7
	Macaranga hypoleuca	1	0.4	11.8
	Macaranga pearsonii	28	22.9	24.0
	Macaranga sp.B	2	2.2	18.2
	Euphorbiaceae Indet sp.B	3	1.8	13.3
Lauraceae	Lauraceae Indet sp.	1	1.3	19.3
Leguminosae	*Fordia* sp.A	1	0.4	11.3
Magnoliaceae	*Magnolia* sp.A	1	0.4	10.7
Moraceae	*Ficus* sp.C	3	0.9	10.4
Myristicaceae	*Knema* sp.B	1	0.9	15.0
Oleaceae	*Chionanthus* sp.B	1	0.4	12.2
	Chionanthus sp.C	1	0.4	13.6
Rubiaceae	*Pleiocarpidia* sp.B	1	0.4	12.4
Sapindaceae	*Nephelium lappaceum*	1	0.4	13.5
Sapotaceae	*Palaquium* sp.A	2	0.9	11.0
Sterculiaceae	*Scaphium longipetiolatum*	1	0.9	15.2
	Sterculia sp.D	1	0.9	17.0
Symplocaceae	*Symplocos fasciculata*	2	1.3	15.0
Thymelaeaceae	*Aquilaria malaccensis*	1	0.4	10.4
Tiliaceae	*Brownlowia peltata*	1	0.4	10.3
	Microcos laxiflora	1	6.7	43.0
Indet	Indet sp.D	1	1.3	20.9
	Indet sp.E	1	1.3	20.4

Logging effects on soil macrofauna in the rain forests of Deramakot Forest Reserve, Sabah, Malaysia

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Abstract We investigated the logging effects on soil fauna in the rain forests of Deramakot Forest Reserve, Sabah, Malaysia and related the abundance and composition of the soil fauna to forest-floor condition and structures of plant communities. Research sites were divided into three categories based on logging intensity as follows: unlogged, reduced-impact logging (RIL) and conventional logging sites. The density of soil macrofauna excluding ants was not different among three logging intensities. The number of the groups (at order or an equivalent taxonomic level) of macrofauna is also similar across the three intensities. The density of ecosystem engineers (earthworms and termites) tended to be higher at the unlogged area. The densities of litter transformer and predators at conventional logging area tended to be higher than those at the other areas. The density of Staphylininae beetles is positively correlated with species richness of trees and the sum of basal area of Dipterocarpaceae. The density of spiders is negatively correlated with species richness of trees, and positively correlated with basal area of *Macaranga*. Diplopoda and Isopoda are negatively correlated with the maximum diameter of trees. Earthworms are positively correlated with the water contents of organic layers. A multivariate analysis CCA (canonical correspondence analysis) was applied to our data set to relate the variation of soil-fauna composition with environmental variables. Water content of forest-floor organic mass and the basal area of Dipterocarpaceae explained the variation of the composition. These results suggested that the abundance and diversity (alpha) of soil fauna were relatively independent of logging, but the composition of functional groups and species composition were affected by logging intensity, and related to plant community or forest floor condition.

Keywords soil macrofauna, functional groups, Deramakot Forest Reserve, ecosystem engineers, termites.

Introduction

Soil fauna plays an important role in every forest ecosystem in the world. Their abundance and diversity are considered to be a good indicator of forest health considering their important roles. In Borneo, the effects of forest management on butterflies (Willott *et al.* 2000), moths (Chey *et al.* 1997), canopy arthropods (Chey *et al.* 1998) and beetles (Chung *et al.* 2000) were investigated. However, there are few studies on the relation between soil fauna and forest management except for the work that investigated termites (Eggleton *et al.* 1999). In contrast, many studies on the relation between soil fauna and forest management have been carried out in the temperate zone of Europe, North America and East Asia. These studies detected that the harvesting method using a clear-cutting scheme caused a substantial change of soil fauna.

The purpose of our study is to determine the patterns of soil fauna in relation to different forest management schemes and recommend a suitable forest management from the standpoint of biodiversity preservation.

Materials and Methods

Ten sites were selected in and around Deramakot Forest Reserve (DFR) and they were categorized based on logging method. The category of "unlogged" had four sites, which were composed of two primary-forest sites and two sites with a history of modest harvest using a selective logging scheme in the 1970s. The category of "RIL" had four sites, which were composed of two sites with a history of the reduced-impact logging (RIL) in 1995 and two sites with RIL in 2000. The category of "conventional logging" had two sites with a history of continuous selective loggings around DFR (see Seino *et al.* in this issue). We established a line (40 m) at each site in September 2003. A quadrat (25 x 25 cm) was set at each of five points at 10 m intervals. Litter layer and topsoil (15 cm) in each quadrate were collected separately. The weight of litter layer and water content were measured after drying samples. Soil animals were immediately picked up from the soil and litter by an insect sucking tube and tweezers in the plot. Animals collected were preserved in 80 % ethanol, and sorted to main groups listed in Table 1 by using a microscope in the laboratory.

Lavelle *et al.* (1995) divided soil macrofauna into two functional groups, namely ecosystem engineers and litter transformers. The former develops mutualism with internal microorganisms and can digest litter directly. Therefore, they affect nutrient cycling or soil formation and are important in ecosystem functioning. Earthworms and termites are included in the ecosystem engineers. The latter contribute to the decomposition of litter in association with external microorganisms. Isopoda, Diplopoda, Blattodea, and Diptera are included in the litter transformer. In addition, predators have also important roles in soil ecosystems. Araneae, Pseudoscorpiones, Opiliones, Geophilomorpha, Symphylla and Lithobiomorpha are the dominant predators. Some groups of ants seem to be predators, but we ignore them from predators in this study, because of the lack of ecological knowledge of ants in this area.

Spearman's rank correlation coefficients were used for the relation between environmental variables and the densities of soil animals. Environmental variables used in this analysis were as follows, tree density, maximum diameters at breast height (DBH) of the trees greater than 10 cm DBH, sum of basal area, above ground biomass of trees, number of tree family, number of tree species, Shannon wiener's diversity index, Fisher's alpha diversity index, basal area percentage of Dipterocarpaceae, basal area percentage of Euphorbiaceae, basal area percentage of *Macaranga*, the weight of organic matter in litter layer and water content of litter layer. Environmental variables of plant communities were precisely explained in Seino *et al.* in this volume.

Principal component analysis (PCA) was used in the analysis of the relation of functional groups and the three categories of logging intensities. Canonical correspondence analysis (CCA) was used for the analysis of the relationship between environmental variables and the community structure of soil animals (ter Braak 1986). The same environmental variables as in the rank correlation analysis were used for this analysis, and forward selection was used to select significant variables ($p < 0.05$).

Results and Discussion

The mean density of total soil macrofauna over all quadrats combined per management scheme is greater at unlogged area (Figure 1). The density of ants was very high at unlogged area, consequently the density excluding ants became similar across three areas. However, we are not sure if the high density is characteristic of the unlogged area because ants are distributed heterogeneously with high standard deviations. We may need another research method for evaluating ant density more precisely (ex. nest counting or bait traps).

Hereafter, we will discuss the pattern of soil fauna excluding ants. The number of groups of macrofauna at order or equivalent taxonomic levels is also similar across all three areas (Figure 2). It seems that our results can represent the abundance of soil fauna for the lowland tropical rain forests of Sabah because the total density and number of groups are in the same order of magnitude as the low elevation on Mt. Kinabalu (Ito *et al.*, 2002). The density of ecosystem engineers tended to be higher at unlogged area (Figure 3). The greater density was due to the high density of termites at unlogged areas. In our study, termites were not divided into feeding groups, nevertheless the most of the termites that occurred in unlogged areas were found in soil layers. Thus, these termites might be dominated by soil feeders. Eggleton *et al.* (1999) suggested that selective logging appears to have relatively little effect on total termite assemblages, but they also found that soil-feeding termites were moderately affected by selective logging. The densities of litter transformers and predators at conventional logging area tended to be higher than at the other areas. PCA ordination of functional groups shows that the unlogged area is placed at a right side on the first axis, in contrast to the conventional area which is placed at a left side (Figure 4). The RIL area is placed between these areas. The eigenvalue of the 1st and 2nd axis is 0.61 and 0.39, respectively. Therefore, the ordination in the two coordinates reasonably well demonstrated the variation of the composition of functional groups. These results suggest that the total density and number of the groups of macrofauna were not much affected by logging within the magnitude of current harvest systems. However, the composition of functional groups was affected by logging methods.

The response of soil fauna to environmental variables was divided into three patterns (Table 2). The first group had a positive correlation with the species richness of trees or with the relative basal area of Dipterocarpaceae. For instance, the density of staphyliniid beetles positively was correlated with the species richness of trees and the sum of basal area of Dipterocarpaceae. The second group had a positive correlation with the relative basal area of *Macaranga*, and associated with disturbed areas after recent logging. The densities of spiders (Araneae), Lithobiomorpha and Pseudoscorpiones were negatively correlated with the species richness of trees, and positively correlated with the sum of basal area of *Macaranga*. For instance, the densities of Diplopoda and Isopoda negatively correlated with the maximum diameter of trees. These groups had a high density at relatively less disturbed areas. The third group correlated with the condition of forest floor in terms of organic mass and water content. The density of Geophilmorpha positively correlated with the amount of organic matter on forest floor. The density of earthworms positively correlated with the water contents of organic layers.

The results of CCA multivariate analysis on the variation of the composition of soil fauna ordinated in relation to the variation of environmental variables (Figure 5) demonstrated that the water content of forest floor mass and the basal area of *Dipterocarpaceae* explained the composition well. The eigenvalue of the 1st and 2nd axes was 0.087 and 0.044; cumulative percentage variance of species data of the 1st and 2nd axes was 26.5 and 40, respectively. This suggested that the community structure of soil macrofauna was influenced by the water condition in forest floor and the dominance of Dipterocarpaceae. Water content is, indeed, suggested as an important limiting factor for the survival of some groups of soil fauna elsewhere (Lavelle *et al.* 2001). In contrast, the importance of the dominance of Dipterocarpaceae, which we found, is not readily known. Probably it reflected the maturity of the forests, which is related to the dynamics of the community of soil macrofauna.

In conclusion, we did not find distinct effects of logging on the total density and the number of taxonomic groups in soil macrofauna. However, the composition of functional or taxonomical groups of soil fauna was related to the composition of above-ground plants or the water contents of organic matter in forest floor. Therefore, logging may influence the relative abundance of assembling soil fauna. We suggest that community composition of soil fauna but neither density nor the number of taxonomic groups has a potential indication value for logging scheme.

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Table 1. Mean densities (m^{-2}) of soil macrofauna in forest sites with different forest managements.

Numbers in fig. 5	Abbreviation of the plot	Category									
		Unlogged				Logged				Conventional	
		PRI-1	PRI-2	70's-1	70's-2	RIL-00-1	RIL-00-2	RIL-95-1	RIL-95-2	CV-1	CV-2
	Platyhelminthes	0	0	0	0	0	0	0	0	3.2	0
32	Gastropoda	3.2	0	0	0	0	0	0	0	0	0
31	Hirudinea	0	0	0	3.2	0	0	3.2	0	0	0
	Oligochaeta (earthworm)	83.2	12.8	48	9.6	28.8	22.4	32	48	64	38.4
	Pseudoscorpiones	28.8	35.2	22.4	28.8	12.8	3.2	38.4	25.6	35.2	35.2
28	Opiliones	3.2	6.4	3.2	0	0	3.2	0	6.4	3.2	3.2
	Araneae (spider)	25.6	57.6	57.6	25.6	16	35.2	60.8	60.8	64	70.4
	Prostigmata	9.6	9.6	3.2	6.4	3.2	3.2	35.2	16	12.8	0
	Gamasida	3.2	12.8	0	3.2	0	3.2	16	9.6	9.6	9.6
	Oribatida	32	16	3.2	3.2	0	3.2	9.6	0	16	6.4
	Isopoda	28.8	12.8	9.6	19.2	6.4	12.8	16	9.6	28.8	73.6
	Diplopoda	32	3.2	19.2	19.2	6.4	12.8	9.6	12.8	25.6	57.6
27	Symphyla	3.2	6.4	6.4	0	0	3.2	0	0	3.2	6.4
	Lithobiomorpha	0	6.4	0	16	6.4	6.4	9.6	3.2	9.6	25.6
	Geophilomorpha	6.4	6.4	9.6	6.4	3.2	3.2	9.6	3.2	6.4	6.4
	Collembola	48	67.2	115.2	28.8	32	44.8	112	92.8	57.6	73.6
	Campodeidae	6.4	9.6	16	0	0	3.2	3.2	9.6	22.4	22.4
	Japygidae	12.8	0	0	0	0	0	3.2	3.2	6.4	16
29	Thysanura	3.2	0	3.2	0	0	0	3.2	9.6	0	6.4
	Isoptera (termite)	688	12.8	70.4	6.4	0	0	3.2	99.2	22.4	0
23	Blattodea	9.6	3.2	0	6.4	0	3.2	9.6	0	9.6	12.8
30	Dermaptera	0	0	0	0	0	0	0	0	6.4	0
25	Other Orthoptera	16	0	6.4	0	0	3.2	0	0	3.2	6.4
7	Hemiptera	22.4	48	41.6	6.4	19.2	9.6	28.8	32	19.2	22.4
22	Lepidoptera (larva)	12.8	6.4	19.2	3.2	0	3.2	3.2	0	0	6.4
15	Pselaphinae	19.2	19.2	0	0	3.2	0	22.4	3.2	28.8	0
	Staphylininae	28.8	9.6	28.8	3.2	9.6	28.8	6.4	19.2	3.2	3.2
10	Other Coleoptera (adult)	32	22.4	16	9.6	28.8	9.6	32	19.2	3.2	28.8
11	Other Coleoptera (larva)	22.4	6.4	19.2	12.8	9.6	12.8	25.6	57.6	22.4	9.6
19	Diptera (larva)	19.2	3.2	6.4	16	0	3.2	12.8	6.4	3.2	0
	Hymenoptera (ant adult)	5357	828.8	656	176	131.2	211.2	172.8	67.2	73.6	364.8
	Hymenoptera (ant larva)	25.6	0	0	3.2	9.6	9.6	0	3.2	0	166.4
	Insecta (unidentified)	6.4	9.6	0	6.4	0	0	0	0	0	6.4
	total density (m^{-2})	6589	1232	1181	419.2	326.4	454.4	678.4	617.6	563.2	1078
	total excluding ants (m^{-2})	1206	403.2	524.8	240	185.6	233.6	505.6	547.2	489.6	547.2
	Number of groups	27	24	21	21	14	22	24	21	26	23

Table 2. Spearman's rank correlation coefficients between densities of each taxon of soil macrofauna and environmental variables. Significant coefficients ($p < 0.05$) are shown in bold.

	Staphylininae	Araneae	Lithobiomorpha	Pseudoscorpiones	Diplopoda	Isopoda	Geophilomorpha	Oligochaeta
Maximum DBH	0.555	-0.526	-0.482	-0.332	**-0.683**	**-0.648**	0.105	-0.419
Total basal areas	0.486	-0.606	-0.537	-0.197	-0.299	-0.367	0.368	-0.219
Above ground boimass	0.312	**-0.661**	-0.352	-0.271	-0.348	-0.447	0.316	-0.413
Species richness of trees	**0.866**	**-0.767**	**-0.756**	**-0.775**	-0.156	-0.469	-0.389	0.043
Relative basal area of Dipterocarpaceae	**0.904**	-0.483	**-0.753**	**-0.689**	-0.146	-0.453	-0.191	-0.043
Relative basal area of Macaranga	**-0.848**	**0.777**	**0.722**	**0.677**	0.152	0.385	0.184	0.055
Weight of litter layers	-0.549	0.287	0.512	**0.720**	0.085	0.447	**0.737**	-0.328
Water contents of litter layers	0.511	0.214	-0.525	0.086	0.354	0.177	0.461	**0.760**

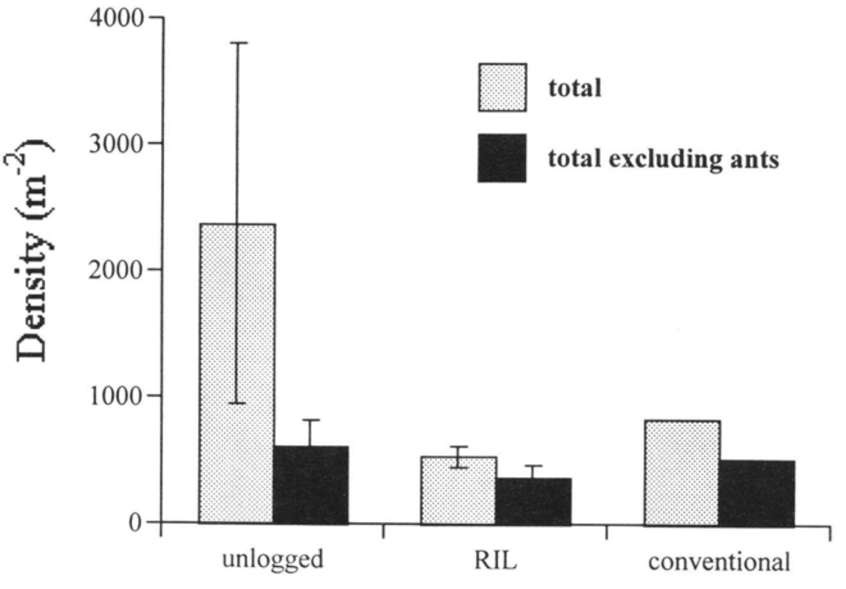

Figure 1. Densities of soil macrofauna in three forest management categories. Bars indicate standard errors.

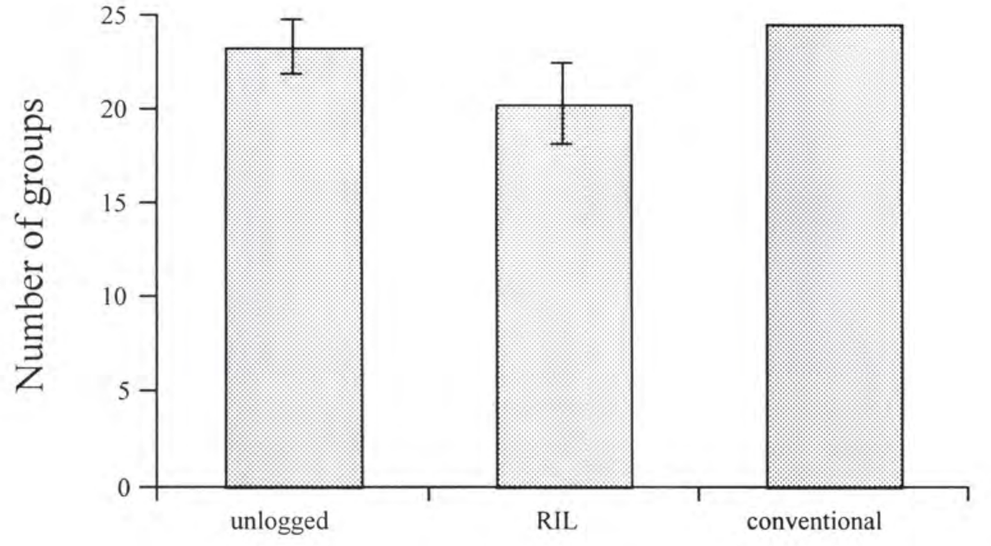

Figure 2. Number of groups of soil macrofauna in three forest management categories. Bars indicate standard errors.

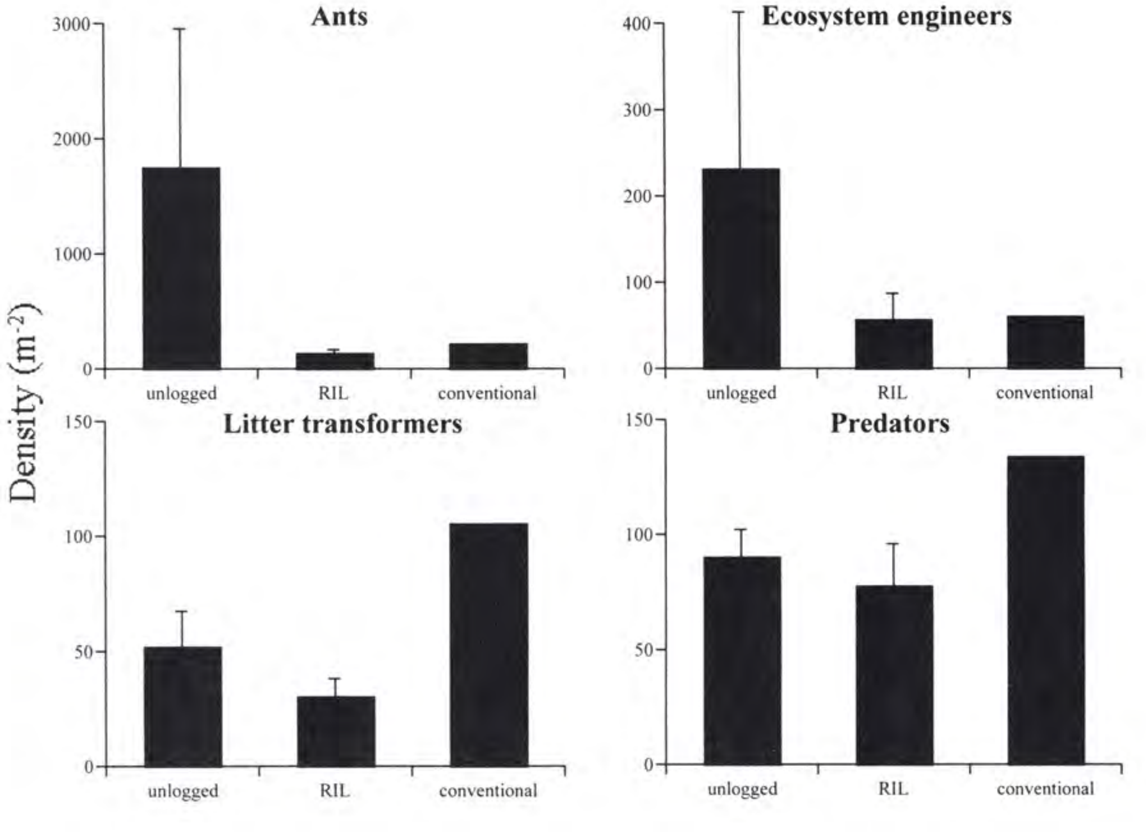

Figure 3. Densities of ants, ecosystem engineers, litter transformers and predators in three forest management categories. Bars indicate standard errors.

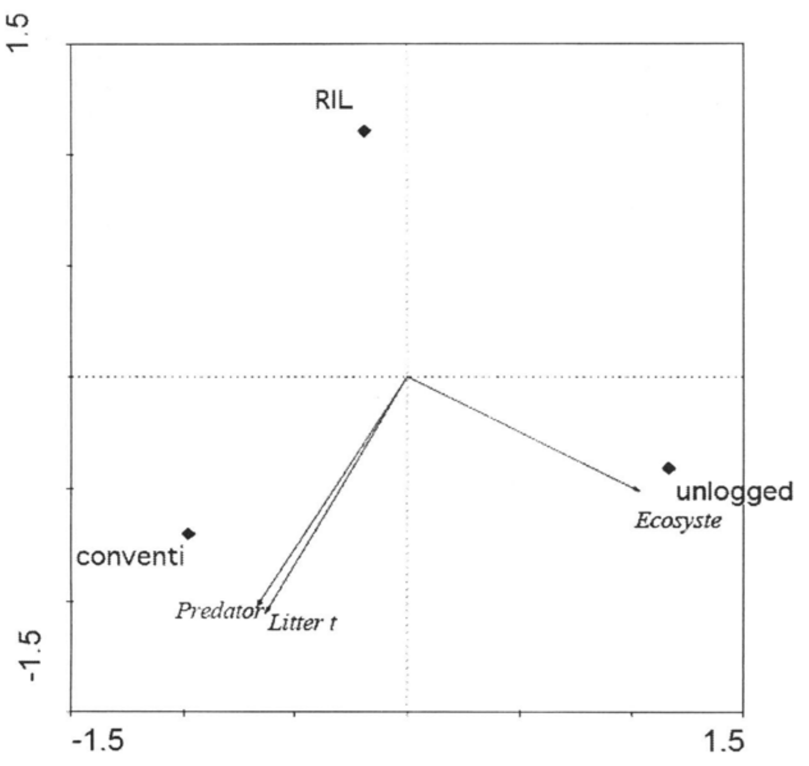

Figure 4. PCA ordination plots for functional groups of soil macrofauna. Diamonds show the positions of communities with forest management categories. Arrows show the directions of the increase of densities for three functional groups.

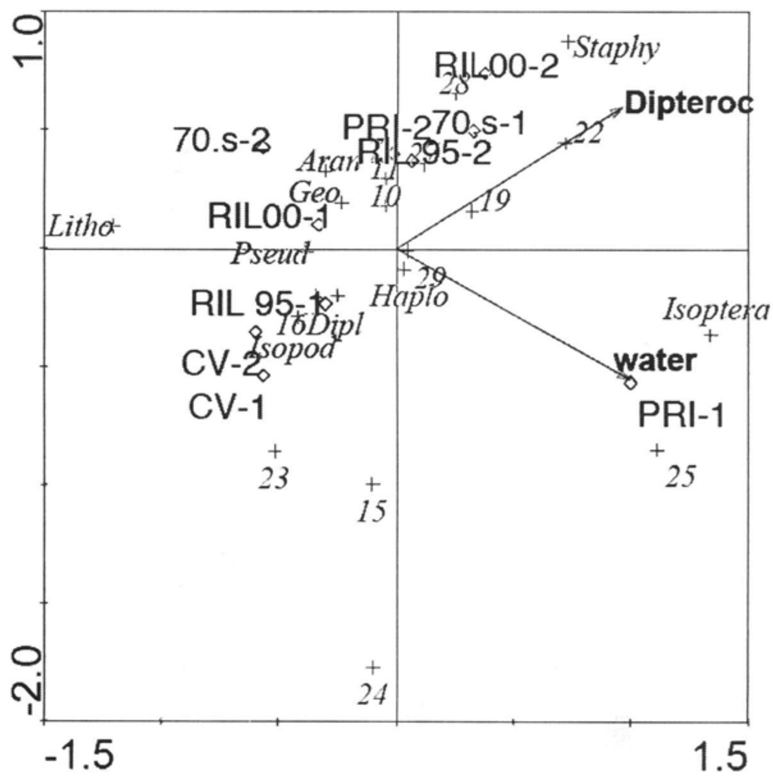

Figure 5. CCA ordination plots for soil macrofauna. Diamonds show the positions of communities with forest managements. Crosses show the positions of the taxonomical groups. Significant environmental variables are shown by arrows. Dipterocap, relative basal areas of Dipterocarpaceae; water, water contents in litter layers; Staphy, Staphylininae; Aran, Araneae; Litho, Lithobiomorpha; Pseud, Pseudoscorpiones; Dipl, Diplopoda; Isopod, Isopoda; Haplo, Oligochaeta. Positions of other animal taxa are shown by numerals, which can be referred in Table 1.

Diversity of mammalian species at natural licks in rain forest of Deramakot and their conservation

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Abstract Natural licks are an important place for mammals to obtain mineral elements that are deficient in their diets. Although the tropical rain forests of Borneo are known for high mammalian diversity, little is known about the relationship between natural licks and mammals. To understand the use of natural licks by mammals and the role of natural licks to maintain the mammalian diversity and populations in Borneo, we conducted a field study in Deramakot Forest Reserve, Sabah. Twenty-nine species of mammals out of the 37 species known in the forests of Deramakot irrespective of food type were recorded on the natural licks. The mammals came to the natural licks to drink water rather than to eat soil. Analysis of the water from the natural licks showed that the concentrations of calcium, magnesium, potassium, and sodium as well as pH were significantly higher than those of the controls (stream and soil water). Foliar analysis of animal diets showed that potassium was significantly higher than sodium in concentration. This study indicated that the mammals might come for the ingestion of minerals, especially sodium, to maintain internal sodium/potassium balance. The natural licks are hot spots of mammalian diversity in Borneo because a cascade of food web (herbivores to carnivores) is formed.

Abstract for policy-makers

Deramakot Forest Reserve has been employing reduced-impact logging techniques, and was certified as a well-managed forest by the Forest Stewardship Council in 1997. Although the forest vegetation and soils have been studied and the techniques to reduce their impacts were incorporated in the reduced-impact logging guidelines, the wildlife has received little attention in forest management. To better achieve the wildlife conservation and the management of forests in Deramakot Forest Reserve, we focused on natural licks, which were known as mammals' gathering place. Little had been known about the relation of natural licks and mammals in Borneo until we started our analysis. Twenty-nine species of mammals out of the 37 species found in the forests of entire Deramakot Forest Reserve with all food types combined were recorded on the natural licks. This study indicated that the mammals might come primarily for the ingestion of sodium to maintain internal sodium/potassium balance. Therefore, natural licks form hot spots of mammalian diversity in Deramakot and probably in other Forest Management Units in Sabah. We propose that the natural licks should be strictly protected for wildlife.

Keywords Borneo, mammalian diversity, natural licks, tropical rain forest.

Introduction

Bornean tropical rain forests are known to be a region of high mammalian diversity. It is important to study the habitat use of mammals in Borneo to understand the tropical forest ecosystem and its conservation. We focused on natural licks, which are thought to be mineral-rich places.

Essential mineral elements in an ecosystem are distributed among several compartments such as soils and above-ground vegetation having distinctive roles and turnover rates. Availability of these mineral nutrients is the product of a complex array of interacting processes including microclimate, chemical properties of organic matter, chemical status of the soil, and the activity of animals. Although most essential elements (nitrogen, phosphate, potassium, calcium, and magnesium) are common in plants and animals, sodium is essential for animals only. Therefore, animals need to rely on natural licks or other mineral sources to overcome the deficiencies in essential elements, including sodium. Many studies on the relation of the chemical properties of natural licks and their use by mammals have been conducted (Blair-West *et al.* 1968; Weir 1972; Botkin *et al.* 1973; Emmons and Stark 1979; Tankersley and Gasaway 1983; Risenhoover and Peterson 1986; McNaughton 1988; Knight *et al.* 1988; Moe 1993; Izawa 1993).

In Borneo, it was reported that the distribution of large herbivores, such as Asian elephants (*Elephas maximus*) and tembadau/banteng (*Bos javanicus*), corresponded with that of natural licks (Payne and Andau 1991). However, little is known about the chemical properties of natural licks and the relationship between natural licks and mammals.

The aim of this study was to understand the use of natural licks by mammals and the significant roles of natural licks in Borneo. We conducted a field study for twelve months between May 2003 and March 2005 in Deramakot Forest Reserve, Sabah, Malaysia.

Materials and Methods

Study area

Deramakot Forest Reserve (05°15'-28'N, 117°20'-38'E) is 55,083 ha and is situated at the upper Kinabatangan River in size, centrally located in Sabah, Malaysian Borneo. The climate is humid equatorial with a mean annual temperature of about 27 °C. Being greatly influenced by the Northeast Monsoon (November-February) and the Southwest Monsoon (May-August), the average annual precipitation is about 3500 mm (Kleine and Heuveldop 1993, Huth and Ditzer 2004). The forest of Deramakot Forest Reserve consists of lowland mixed dipterocarp forests dominated by the family Dipterocarpaceae (*Dipterocarpus* spp., *Parashorea* spp., and *Shorea* spp.).

Under the management of the Forestry Department of Sabah, harvesting operations within Deramakot Forest Reserve has been following reduced-impact logging guidelines since 1995 and the reserve was certified as a well-managed forest by the Forest Stewardship Council in 1997. Although the forest vegetation and soils have been studied and incorporated in the reduced-impact logging guidelines, the wildlife has received less attention in forest management.

Mammal survey at natural licks and other places in Deramakot Forest Reserve

We surveyed the mammalian species in Deramakot Forest Reserve, targeting the medium and large, non-volant mammalian species using 1) a 24-hour camera-trap with 15 camera stations, 2) a route census: diurnal direct-observation and identification of prints (footprints and claw marks), and 3) interviews with knowledgeable forestry staff of Deramakot District. Target species were 47 species that have been recorded in lowland forest, Sabah (Yasuma and Andau 2000). Chiroptera (bats), Dermoptera (colugo), Small Insectivora (shrews), Scandentia (treeshrews), and Small Rodentia (squirrels and rats) were excluded from this study.

Camera traps with an infrared triggering mechanism (sensor camera Field note II, Marif, Yamaguchi, Japan) were set up at 15 camera stations, which included 10 animal trails near watering places or on a ridge and five natural licks. Some camera traps were baited with fallen fruits. After completion of the field study, we counted the numbers of individuals photographed. When there were many photographs of the same individual within 30 minutes, only one was counted. When several individuals were photographed in one frame, only one was counted. For the route census, we established 6 routes with a total of 64 km: a path to get to camera-trapping sites; a 3 km course around the base camp; a 15 km path west of the base camp; a 10 km path north of the base camp; a 30 km path and two 3 km paths east of the base camp. We conducted a route census on foot, by motorbike, or from four-wheel vehicles during the day and night. For interviews, we relied on very knowledgeable Forestry Department employees.

Chemical properties of natural licks and animals foods

The study identified five natural licks within Deramakot Forest Reserve: NL-1 (05°22'N, 117°29'E), NL-2 (05°20'N, 117°30'E), NL-3 (05°21'N, 117°31'E), NL-4 and NL-5 (05°19'N, 117°34'E) (Figure 1); the label number indicating the distance of the natural licks, in kilometers, from the Forestry Department Base Camp. To study the chemical properties of the natural licks, we analyzed the mineral contents of the water from the natural licks. A total of 59 water samples were collected from the natural licks: 13 from NL-1, 13 from NL-2, 11 from NL-3, 13 from NL-4, and 9 from NL-5 at different times and seasons. For comparison, we also collected 18 samples of water, 8 from a pond and 10 from a stream less than 50 m from natural licks NL-1 and NL-4. During each collection, water samples were drawn through a 10 ml pipette from more than 10 points at each natural lick, pond or stream and bulked by site. After thorough mixing to homogenize, about 50 ml of each bulked samples was filtered (syringe filter 0.2 µm pore size, Whatman, USA) and stored at 4 degrees Celsius until the time of the analysis.

To test the chemical properties of the animal diets based on mammal survey at the licks, we collected some creeping herbs (Leguminosae: *Mimosa pudica*), some herbaceous vines (Compositae: *Mikania scandens*), grass (Gramineae: *Paspalum conjugatum*), young leaves of trees (Euphorbiaceae: *Macaranga* spp.), fallen fruits (Moraceae: *Ficus* spp.; Rubiaceae: *Neolamarckia cadamba*), and bark of trees (Sterculiaceae: *Pterospermum* spp.). The plant samples were dried at 60 degrees Celsius to a constant weight and then ground to pass a mesh size of 1 mm using a Thomas Wiley Mill. The ground samples were then digested following the sulphuric acid-hydrogen peroxide method described in Allen (1989).

Total calcium, magnesium, potassium, and sodium concentrations in the filtered water samples and the digested solutions were measured on a GBC atomic absorption spectrometer. Prior to the measurement, the temperature of the water samples was brought to room temperature. All of the analyses were conducted at the Chemistry Section of the Forest Research Centre, Sabah Forestry Department.

Data analysis

Comparisons of the chemical properties of natural licks with controls as well as the sodium and potassium concentrations in vegetative diets of the animals which visited natural licks were statistically conducted through analysis of variance followed by a comparison of means. Data are presented as the mean $\pm$ standard deviation.

Results

Mammalian fauna of Deramakot Forest Reserve

Table 1 shows the species of medium-to-large mammals recorded in Deramakot Forest Reserve. Seven orders, seventeen families, and thirty-seven species were recorded during the census. The number of species from this study accounts for 78.7% of the total targeted species (47 species). Large endangered mammals, such as the orang-utan (*Pongo pygmaeus*), the Asian elephant, the clouded leopard (*Neofelis nebulosa*), and the sun bear (*Helarctos malayanus*), were recorded in a wide area. The tembadau/banteng was confined to a relatively small area in the eastern part of Deramakot Forest Reserve. Proboscis monkey (*Nasalis larvatus*) was recorded at the Kinabatangan riverside, in the south and southeastern parts of Deramakot Forest Reserve. Some animals were recorded with their young ones by direct observations, or camera traps or with the evidence of dung. These results showed that

Deramakot Forest Reserve has breeding populations of large endangered mammals.

Mammalian species and their behavior at natural licks

Table 1 also shows that 29 mammalian species (78.4%) out of the 37 in Deramakot Forest Reserve were recorded at natural licks during the census. The number of species accounts for 61.7% of the total number of species (47 species) in Sabah. This survey showed that diurnal and nocturnal, or terrestrial and arboreal mammals with all food-types came to natural licks.

A total of 493 photographs were taken by five camera traps at five natural licks (472 camera-nights). Table 2 shows the top-five mammal species in descending order according to the number and frequency of photographs. The sambar deer (*Cervus unicolor*) (42.8%; n = 211), followed by the bearded pig (*Sus barbatus*) (18.5%; n = 91), was the most commonly recorded species in all photographs (n = 493). The orang-utan, the Asian elephants (*Elephas maximus*), and the tembadau/banteng (*Bos javanicus*) which were endangered species, were also recorded to use a natural lick. (Figure 2-1, 2-2 and 2-3).

The results of camera traps, direct observations and interviews, and the absence of excavation prints suggested that the mammals drink the water rather than eat the soils.

Chemical properties of natural licks and the animal diets

The natural licks of Deramakot Forest Reserve are around 3.5±2.5 m^2, usually contain little water and connected to some animal trails. Although there is variation in the mineral concentrations of natural licks, water samples from natural licks had significantly higher ($p < 0.001$) pH levels and calcium, magnesium, potassium, and sodium concentrations than those from controls did (Table 3). The sodium concentration of NL-4 and NL-5 were significantly higher than that of the other natural licks ($p < 0.001$). Moreover, the NL-4 and NL-5 only has a large colony of leeches in the water. The leeches were thought to be waiting for animals, whereby they cling to the muzzle and suck their blood (interview with local people). Only at the NL-2, calcium demonstrated the highest concentration among minerals. These results indicate that the natural licks could be classified by the mineral concentration and presence of the leeches. The mineral contents of the animal diets indicated that the potassium concentration was the highest of all, except for bark of the tree (Table 4). Moreover, Table 4 shows that potassium was significantly higher than sodium in concentration ($p < 0.001$).

Discussion

Visitation of herbivorous/frugivorous animals to natural licks in Borneo

Mammals of all food types, i.e., herbivorous/frugivorous, insectivorous, omnivorous, and carnivorous animals, were recorded at natural licks. In addition to the sambar deer, the lesser mouse-deer, and the orang-utan, which were in the top-five species (Table 2), the Asian elephants and the tembadau/banteng were confirmed at all natural licks. These results suggest that these species including endangered species largely depend on natural licks and that their spatial concentrations in the forest must be influenced by the distribution of natural licks.

An analysis of the chemical properties of natural licks and the food available for them showed that 1) the pH of the water was alkaline and 2) the food taken by herbivore/frugivore animals had significantly higher potassium than sodium in concentration. It has been reported that herbivore/frugivore animals suffer from acidosis as a result of the acceleration of fermentation in their stomachs (Kreulen 1985). These results suggest that some of the reasons that herbivore/frugivore animals come to natural licks: 1) to drink alkaline water to avoid acidosis, and 2) to ingest sodium to maintain the internal sodium/potassium balance.

Visitation of omnivorous and carnivorous animals to natural licks in Borneo

Not only herbivorous/frugivorous animals but also omnivorous/carnivorous animals, such as the bearded pig and the Malay badgers (*Mydaus javanensis*), were in the top-five species (Table 2). These omnivorous/carnivorous species can obtain sodium from prey animals. Omnivorous and carnivorous animals have also been recorded at natural licks in Nepal (Moe 1993). The reason for their visiting natural licks is not clear. Considering that natural licks usually have little water, they may not primarily come to drink the water. Rather, they might use natural licks as hunting places. Bearded pigs and Malay badgers generally eat earthworm and insects, although bearded pigs have a varied diet. They might also come to natural licks to forage their food because some insects, such as butterflies, bees, and dung beetles, also use natural licks to ingest mineral water and forage animal dung. Using camera traps, we also recorded small mammals such as bats, treeshrews, squirrels, and rats at natural licks; however, we did not focus on them in this study owing to the difficulty of identifying them in the photographs. They also might come to eat earthworms and insects. Moreover, civets, mongooses, and wild cats were also recorded at natural licks (Table 1). They might come to natural licks to hunt these small animals. These relations suggested that food-chain cascades (soil fauna and insects — small mammals — medium-to-large omnivorous/carnivorous animals) might be formed at natural licks. Further research on the fauna at natural licks would clarify the food chain.

Importance of natural licks in Deramakot and its possibilities

This study suggests that natural licks have the following functions for mammals in Deramakot Forest Reserve: 1) to supply alkaline water, 2) to supply minerals, especially sodium, and 3) probably, to provide a hunting place for predatory mammals. From these, we conclude that natural licks are a hot spot of mammalian diversity in Deramakot and probably elsewhere in Borneo. Results of interviews with local people suggest that such natural licks are not only present in Deramakot Forest Reserve but also in other forest areas in Sabah, Borneo. Therefore, natural licks should be strictly protected as an important habitat to keep mammalian diversity in Deramakot Forest Reserve. At present, Sabah Forestry Department is progressing towards protecting and conserving the identified natural licks.

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Table 1. Medium to large mammal fauna in Deramakot Forest Reserve.

Order	Family	Species (Scientific name)	Main food habit*
Insectivora	Erinaceidae	Moon rat (*Echinosorex gymnurus*)	I
Primates	Lorisidae	Slow loris (*Nycticebus coucang*)	O
	Tarsiidae	Western tarsier (*Tarsius bancanus*)	I
	Cercopithecidae	Red leaf monkey (*Presbytis rubicunda*)	H
		Silvered langur (*Presbytis cristata*)	H
		Proboscis monkey (*Nasalis larvatus*)	H
		Long-tailed macaque (*Macaca fascicularis*)	O
		Pig-tailed macaque (*Macaca nemestrina*)	O
	Hylobatidae	Bornean gibbon (*Hylobates muelleri*)	H
	Pongidae	Orang-utan (*Pongo pygmaeus*)	H
Pholidota	Manidae	Pangolin (*Manis javanica*)	I
Rodentia	Hystricidae	Long-tailed porcupine (*Trichys fasciculata*)	H
		Common porcupine (*Hystrix brachyura*)	H
		Thich-spined porcupine (*Thecurus crassispinus*)	H
Carnivora	Ursidae	Sun bear (*Helarctos malayanus*)	O
	Mustelidae	Yellow-throated marten (*Martes flavigula*)	C
		Malay badger (*Mydaus javanensis*)	C
		Oriental small-clawed otter (*Aonyx cinerea*)	C
	Viverridae	Malay civet (*Vierra tangalunga*)	O
		Otter-civet (*Cynogale bennettii*)	C
		Binturong (*Arctictis binturong*)	O
		Masked palm civet (*Paguma larvata*)	O
		Common palm civet (*Paradoxurus hermaphroditus*)	O
		Banded palm civet (*Hemigalus derbyanus*)	O
		Short-tailed mongoose (*Herpestes brachyurus*)	C
	Felidae	Collared mongoose (*Herpestes semitorquatus*)	C
		Clouded leopard (*Neofelis nebulosa*)	C
		Flat-headed cat (*Felis planiceps*)	C
		Leopard cat (*Felis bengalensis*)	C
Proboscidea	Elephantidae	Asian elephant (*Elephas maximus*)	H
Artiodactyla	Suidae	Bearded pig (*Sus barbatus*)	O
	Tragulidae	Lesser mouse-deer (*Tragulus javanicus*)	H
		Greater mouse-deer (*Tragulus napu*)	H
	Cervidae	Bornean yellow muntjac (*Muntiacus atherodes*)	H
		Red muntjac (*Muntiacus muntjak*)	H
		Sambar deer (*Cervus unicolor*)	H
	Bovidae	Tembadau/Banteng (*Bos javanicus*)	H

*: C: Carnivore; H: Herbivore; I: Insectivore; O: Omnivore
Underlined indicates confirmed mammals at natural lick.

Table 2. Top five species of photographed mammals at the natural licks.

Species (Scientific name)	Number of photographs	Percentage
Sambar deer (*Cervus unicolor*)	211	42.8
Bearded pig (*Sus barbatus*)	91	18.5
Lesser mouse-deer (*Tragulus javanicus*)	37	7.5
Malay badger (*Mydaus javanensis*)	23	4.7
Orang-utan (*Pongo pygmaeus*)	23	4.7

Table 3. Mineral concentrations and pH of the natural licks in Deramakot Forest Reserve.

Locations (Number of Samples)	Minerals: ppm ± *SD*				pH ± *SD*
	Ca	Mg	K	Na	
NL-1 (13)	41.7±4.7	16.5±1.7	6.8±3.2	42.6±10.2	7.9±0.3
NL-2 (13)	94.0±9.3	23.2±1.9	8.4±3.0	38.7±4.6	8.0±0.3
NL-3 (11)	45.1±7.2	15.0±2.0	12.1±3.4	47.2±18.2	8.0±0.2
NL-4 (13)	155.9±51.6	35.1±11.6	29.8±12.6	2710.2±889.1	7.9±0.2
NL-5 (9)	70.5±10.8	13.6±2.4	14.6±17.9	1166.3±253.1	8.2±0.2
Mean of Natural Licks ± *SD*	83.4±50.0	21.4±9.8	14.4±12.6	801.8±1173.5	8.0±0.3
Control-1 (8)	5.6±2.6	2.3±1.1	1.8±0.8	4.6±1.9	7.2±0.6
Control-2 (10)	20.4±4.9	3.1±0.8	1.5±0.2	8.7±0.7	7.9±0.2
Mean of Control ± *SD*	13.8±8.5	2.7±1.0	1.6±0.6	6.9±2.4	7.6±0.5

Table 4. Mineral concentrations of the animal diets.

The diets (Scientific name)	Minerals: mg/g			
	Ca	Mg	K	Na
Creeping herb *Mimosa pudica*	3.26	2.18	16.97	0.09
Herbaceous vine *Mikania scandens*	1.50	1.50	17.08	0.37
Grass *Paspalum conjugatum*	1.91	2.60	20.49	0.11
Young leaf *Macaranga* spp.	5.29	4.10	16.63	0.05
Fruit 1 *Ficus* spp.	14.71	1.99	21.55	0.22
Fruit 2 *Neolamarckia cadamba*	2.05	1.14	15.78	0.11
Bark of the tree *Pterospermum* spp.	15.42	0.76	7.10	0.27
Mean ± *SD*	6.31 ± 6.1	2.04 ± 1.1	16.51 ± 4.7	0.17 ± 0.1

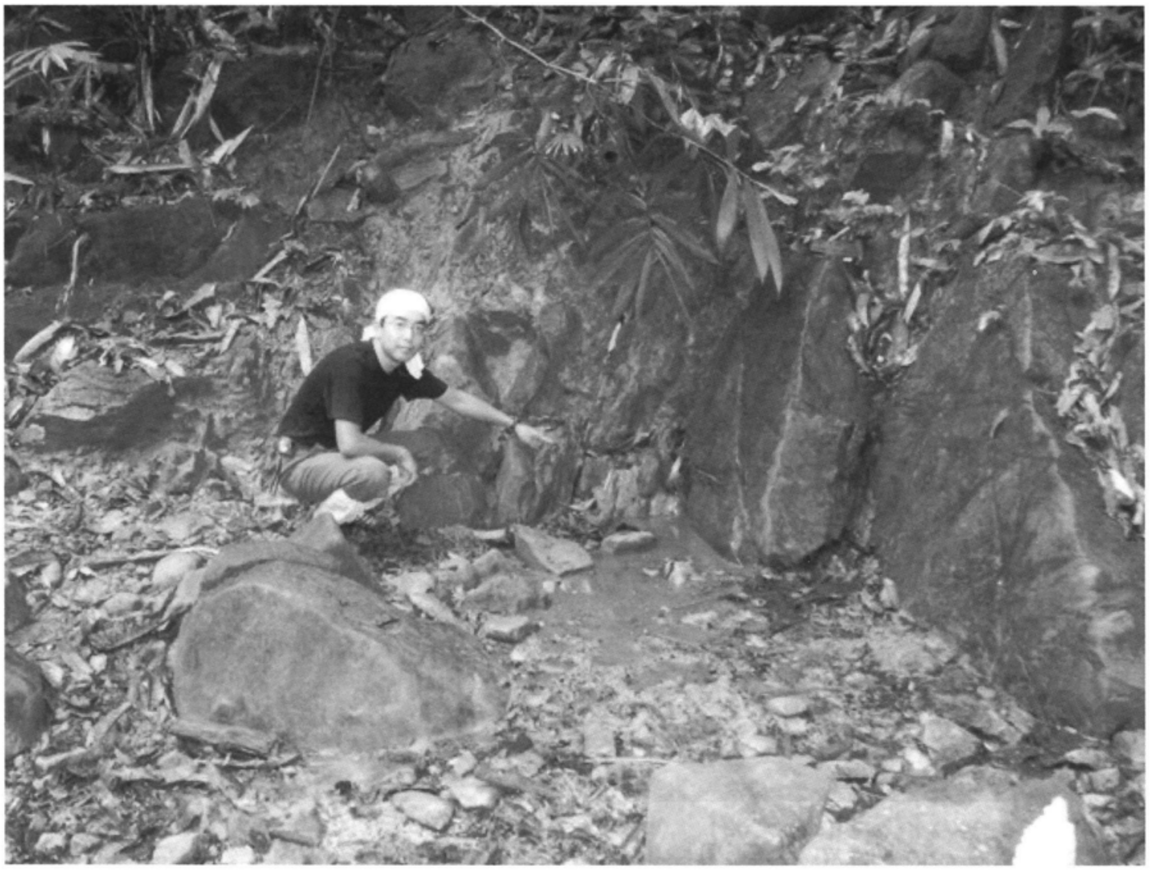

Figure 1. A natural-lick in Deramakot Forest Reserve.

Figure 2-1. Photographed animals at the natural licks. Adult male orang-utan.

Figure 2-2. Photographed animals at the natural licks. Adult female Asian elephant.

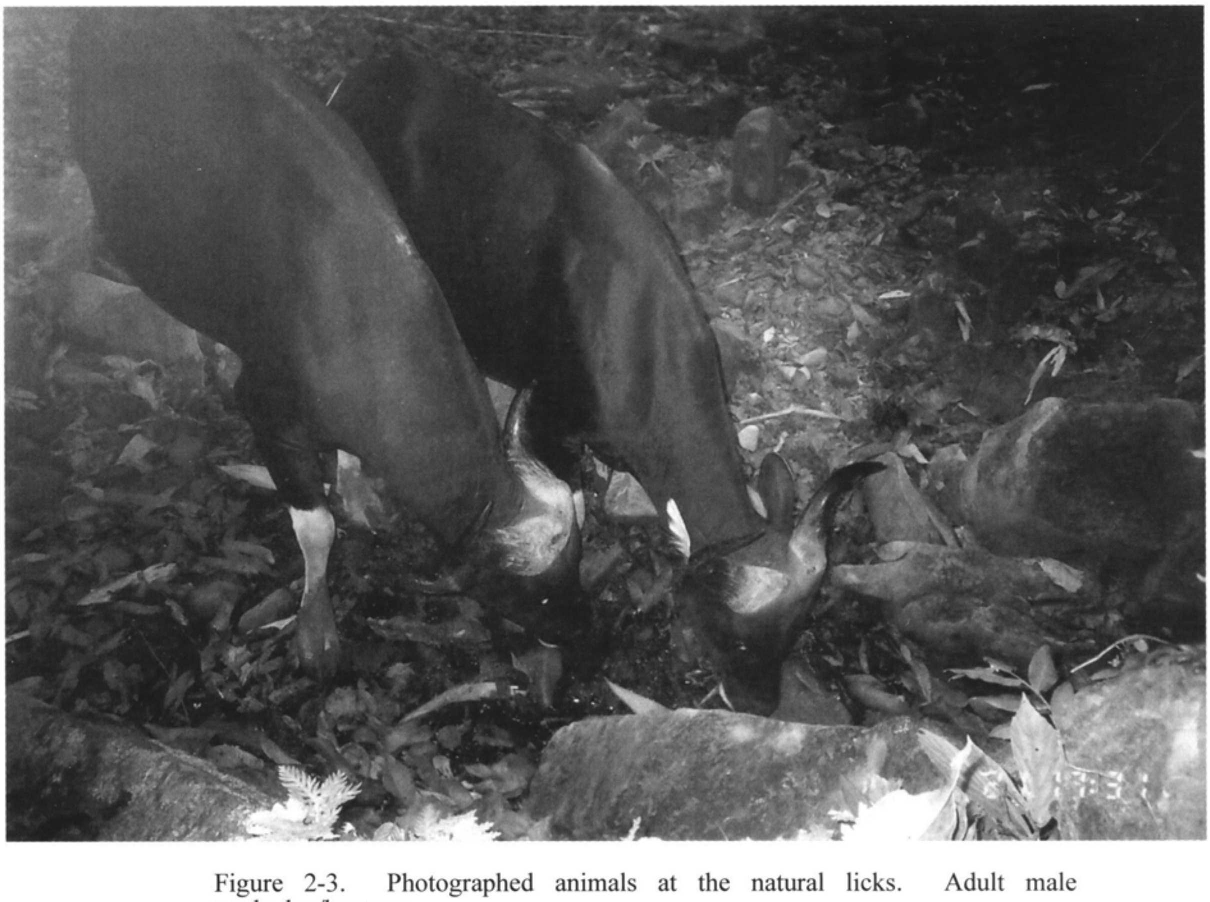

Figure 2-3. Photographed animals at the natural licks. Adult male tembadau/banteng.

Assessment of the bioindicator values of flying insects at a higher taxonomic level for different logging schemes in the lowland tropical rain forests of Deramakot, Sabah, Malaysia

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Abstract The importance of the ecosystem services of, and the biological values of tropical forests are increasingly recognized amid drastically changing landscapes in the tropics. There is an urgent demand for establishing an appropriate environmental assessment method to keep healthy ecosystem functions and biodiversity along with sustainable forest use based on ecological principles. In this study, we tried to assess logging disturbance using several flying insect groups with their abundance in managed lowland tropical rain forests, Deramakot Forest Reserve (DFR), Sabah, Malaysia, with consideration of seasonal changes. We used a bait trap system to collect flying insects in several strata from the ground to a canopy in four seasons (periods) throughout a year in five forests with different logging histories/intensities. All the studied insects at a lower taxonomic level fluctuated seasonally in their abundance, while the family composition which took into account the relative abundance of families of trapped insects was relatively constant across the plots and the seasons. Although, effects of logging on the abundance of flying insects were distinct at an intensively logged plot, there was no clear difference among undisturbed plot and the moderately disturbed plots harvested by reduced-impact logging (RIL). The abundance of flying insects at higher taxonomic level has a potential of indicating logging disturbance.

Introduction

An alteration of tropical forests has been an issue in conservation ecology since the 1980s (Bowles *et al.*, 1998). The importance of ecosystem services and biological values provided from tropical forests has been pointed out by scientists and more recently citizens are increasingly aware of the importance of tropical forests. Therefore, scientific knowledge can be better disseminated to the society for the sustainable use of tropical forests in the world. Main driving forces of deforestation are population pressure, policies of governments (Laurance, 1998) or economic development (Wilkie *et al.*, 1992) and combinations of these. Under these circumstances, it is a challenging task for us to develop policies and schemes of the conservation of tropical forests to keep healthy ecosystem functions and biodiversity in harmony with the sustainable use of these forests (Kleine and Heuveldop, 1993). To achieve this goal, we need to demonstrate the tolerance level of forests for human use based on ecological principles (Bawa, 2004).

The first step to meet this challenge is to scientifically and practically assess the current conditions of disturbed and undisturbed environments. Various bioindicators have been applied as useful tools to assess living conditions for organisms, traditionally in aquatic environments (Rosenberg *et al.*, 1986) and recently in terrestrial environments (Van, 1998; Baldi, 2003; Ekschmitt, 2003 Woodcock *et al.*, 2003). Invertebrates have an advantage as bioindicators, because of being ubiquitous in a wide range of environments and of being moderate in the growth rate, population turnover and mobility to record (Hodkinson *et al.*, 2005).

There are various approaches in bioindicator assessment. Some focus on certain taxa, but others measure the diversity of the whole community at the level of species or higher taxa (McGeoh, 1998; Hodkinson *et al.*, 2005). Naturally, the finer the taxonomic resolution is, more fine-scaled information on the environment will be gained. However, such a fine-scale assessment at the species level is impractical when using highly diverse taxa such as insects. Identification of species is almost impossible for non-experts and even for experts the identification work necessitates a large amount of labor and time (Oliver, 1996; Lawton *et al.*, 1998; Baldi, 2003; Keith, 2004). Instead, practically and economically reasonable approaches of using higher taxa (family or order) or functional groups are recently invented and demonstrate scientifically reasonable results (Baldi, 2003; Deans, 2005).

In this report, we present preliminary results of our study carried out in Deramakot Forest Reserve (DFR), Sabah, Malaysia from 2003 to 2004. In DFR, various logging regimes were historically applied to different stands of tropical lowland rain forests. Effects of different degrees of logging disturbance on insect abundance were compared across an array of forest stands that differ in the method of logging operation and the time elapsed after logging.

Materials and Methods

Location and climate of study site

Deramakot Forest Reserve (DFR), Sabah, Malaysia (5°19'- 20'N, 117°20'-42'E), covers 55,000 hectares in the east of central Sabah. The climate is humid equatorial, with low variance in monthly mean temperature with a monthly mean of about 26°C. Although the climate is humid equatorial, monthly rainfall fluctuates seasonally, being higher in November to February but lower in March to July by the Northeast and Southwest Monsoon, respectively (Town and Regional Planning Department, Sabah, 1998). The forest of DFR is classified as the *Parashorea tomentella-Eusideroxylon zwageri* type, dominated by dipterocarps such as *Parashorea tomentella*, *Shorea johorensis*, *Dryobalanops lanceolata* and *Dipterocarpus caudiferus*, which together make up 40 % of bigger trees (Chey, 2002).

Logging history in DFR

Logging in DFR began from the southern part, along the Kinabatangan River, in the 1950s. The initially adopted logging method was the Malayan Uniform System, which allowed harvesting of all commercial timber over 45 cm in DBH (Diameter at Breast Height) and following systematic poisoning to unwanted species for promoting the natural regeneration of saplings and seedlings of commercial trees. This was modified in 1971 to the Sabah Uniform System along with the timber boom that started in the late 1960s (Kleine and Heuveldop, 1993). In the Sabah Uniform System, the minimum DBH for harvesting was raised to 60 cm and felling was assumed to be at 60-year intervals. As a result of the use of heavy machineries and intensity of logging, a large tract of the forests of Sabah was altered.

In 1989, the Sabah Forestry Department, assisted by the German Government, started a project aimed at introducing sustainable management for timber production, soil conservation, non-timber forest produce and conservation of native flora and fauna in DFR. The introduced logging operation is called reduced-impact logging (RIL). RIL is a kind of selective logging, which lays down various guidelines for sustainable forest use, e.g., setting of stream buffer zones, preservation of potential crop trees, and damage assessment after harvesting (Sabah Forestry Department, 1998).

Study plots

To assess the recovery from and the impacts of logging on various components and functions of lowland tropical rain forest ecosystem, a total of ten 0.2-hectare study plots were established in different forest compartments in and near DFR by colleagues of plant ecology (see Seino *et al.* in this volume): those plots were classified into five groups, each with two replicate plots, under different regimes of disturbance (i.e. harvest method) in logging operation and the time elapsed after logging. We chose one of the two replicate plots from each group for sampling flying insects. In this paper, the disturbance regimes were specified by two factors, logging method (RIL or CM (conventional method) referring to non-RIL) and the time after logging. The five plots for insect collection were named according to the disturbance regimes: Primary, the forest with no impact of logging (5°22'7.1"N, 117°25'9.73"E); CM-70s, the forest harvested in the 1970s by CM (5°22'2.26"N, 117°26'1.96"E; No. 54); RIL-95, the forest harvested in 1995 by RIL (5°21'5.42"N, 117°25'4.45"E; No. 60); RIL-00, the forest harvested in 2000 by RIL (5°23'8.88"N, 117°18'9.5"E; No. 63); and CM-con, the forest intermittently continuously harvested by CM (5°23'8.64"N, 117°18'9.19"E; outside of DFR).

Insect sampling

We employed a bait trap specially designed by Toda (1977) for sampling flying insects in the above-ground forest space. To collect mainly fruit flies (Drosophilidae) the traps were baited with fermented banana (ca. 170 g per trap), but non-drosophilid flies (Diptera), beetles (Coleoptera), bees and wasps (Hymenoptera) were also collected in abundance. Insects of other orders were also collected but with lesser abundance.

In order not to disturb the forest floor of study plots by repeated visits to the trapping sites, we selected a tree or two trees beside each plot for setting the banana traps. The traps were set vertically from the understory to the canopy: the lowest trap was set at 0.5 m above the ground surface, the next at 1.5 m, and others at 5 m intervals up to the canopy with the top trap varying in height according to the canopy height of the forest (Table 1). Some (up to four) upper traps were suspended from the same rope with a pulley that was hung from a bough of the selected tree, but the lowest two were tied directly to the trunk of the same or a nearby tree (Figure 1).

We conducted sampling four times, in July to August and in October to November 2003, and in January to February and in April to May 2004. During each sampling period trapped insects were collected and trap baits were renewed three times at 10-day intervals. All samples were preserved in 70 % ethanol and temporarily brought to Hokkaido University (Japan) for identification purposes. Collected insect specimens were identified to family for Diptera and Coleoptera but to order for the others except Hymenoptera, which was classified into honey bee, stingless bee and parasitic wasp.

Results and Discussion

We collected, in total, 82,318 individuals of ten orders by the four monthly samplings: 20,514 individuals of 8 orders in July to August, 27,393 individuals of nine orders in October to November, 17,662 individuals of nine orders in January to February and 16,749 individuals of nine orders in April to May. Table 2 shows the numbers of individuals of each family (functional group for Hymenoptera) or order collected at the five study plots in each sampling period. Since the number of traps varied among the study plots (Table 1), the abundance of trapped arthropods at each plot was expressed as the number of individuals collected per trap in Figure 2.

The abundance of trapped arthropods varied among the plots and seasons. The difference among the plots was large (more than 130 in standard deviation) in relatively dry seasons (July to August, October to November and April to May) and small (21.5 in standard deviation) in the rainy season (January to February). Such clear seasonality has been observed in the abundance of tropical insects (Wolda, 1980; 1988; Kato *et al.*, 1995). This suggests that even in the tropics, environmental assessment using arthropods community should be done across a year. Although the abundance-rank orders of the plots varied among the seasons, in general, moderately disturbed plots, RIL-95 or RIL-00, had the most abundant number of trapped insects and the heavily disturbed plot, CM-con, had the least number of insects.

In spite of the variation in total abundance, the composition using relative abundance of families of trapped arthropods was relatively constant across the plots and the seasons. Drosophilidae, Nitidulidae and Staphylinidae in combination made up nearly 90 % of the total catch at every plot. This may indicate the efficiency of bait traps for collecting insects from distance. Further precise identification of the collected samples (i.e. species level) is need for evaluating the changes of community structure along with logging disturbance regimes.

We suggest that the bait trap method which we have used here can effectively collect flying insects with minimal support from various strata of a tropical forest. Abundance of collected arthropods was prominently decreased at heavily disturbed plot, CM-con. Relatively cost effective assessment of using bioindicator at higher-taxonomic level has a potential of evaluating logging disturbance. We are still identifying collected insects for selecting taxa of such bioindicator values. Our results will be reported elsewhere.

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Table 1. Summary of trapping site at each study plot.

Plot	Canopy height (m)	Species of trap-site trees	Trap heights (m)
Primary	31.5-36.5	*Polygclaccae affine* *Shorea exelliptica*	0.5, 1.5,6.5, 11.5, 16.5 21.5, 26.5, 31.5, 36.5
CM-70s	26.5-31.5	*Lithocarpus sp.* *Shorea macroptera*	0.5, 1.5,6.5, 11.5, 16.5,21.5 26.5, 31.5
RIL-95	26.5-31.5	*Shorea sp.*	0.5, 1.5, 6.5, 11.5, 16.5, 21.5, 26.5
RIL-00	26.5-31.5	*Dipterocarpus sp.* *Durio* sp.	0.5, 1.5, 6.5, 11.5, 16.5 21.5, 26.5
CM-con	21.5-26.5	*Shorea parvifolia*	0.5, 1.5, 6.5, 11.5, 16.5, 21.5

Table 2. Numbers of arthropod individuals collected in July to August, in October to November, 2003, in January to February and in April to May, 2004, separately shown for each family or order.

Order	Plot Family	Primay	CM-70s	RIL-95	RIL-00	CM-con
July to August						
Diptera	Drosophilidae	3346	3053	1891	3378	1061
	Phoridae	169	60	96	164	116
	Sciaridae	16	3	4	6	6
	Muscidae	16	10	6	19	6
	Neriidae	29	2	1	1	6
	Total	3576	3128	1998	3568	1195
Coleoptera	Nitidulidae	1375	717	816	908	290
	Staphylinidae	618	601	361	346	328
	Lucanidae	0	32	9	1	0
	Curculionidae	2	1	0	0	0
	Scolytidae	7	1	1	0	7
	Total	2002	1352	1187	1255	625
Hymenoptera	Parastic wasp	95	66	41	104	51
	Honey bee	3	1	1	0	0
	Stingless bee	52	42	34	53	35
	Wasp	4	1	0	2	0
	Total	154	110	76	159	86
Hemiptera		1	0	0	0	0
Blattaria		2	4	7	8	4
Lepidoptera		2	2	0	0	3
Araneae		2	4	1	1	1
Orthoptera		0	0	0	1	0
	Total	5739	4600	3269	4992	1914
October to November		4735	2289	3822	2576	2132
Diptera	Drosophilidae	195	241	139	151	97
	Phoridae	83	85	23	71	2
	Sciaridae	13	6	21	13	3
	Muscidae	6	3	2	24	5
	Neriidae	12	2	8	4	0
	Syrphidae	5044	2626	4015	2839	2239
	Total	2240	764	1968	1409	955
Coleoptera	Nitidulidae	396	376	293	370	350
	Staphylinidae	1	3	0	18	0
	Lucanidae	1	3	3	0	4
	Curculionidae	2	3	5	1	3
	Scolytidae	4	0	0	0	1
	Histeridae	1	0	0	5	0
	Total	2645	1149	2269	1803	1313
Hymenoptera	Parastic wasp	246	212	199	321	174
	Honey bee	4	2	8	1	1
	Stingless bee	28	56	15	29	26
	Wasp	2	2	0	0	0
	Total	280	272	222	351	201
Hemiptera		21	8	12	22	2
Blattaria		2	15	10	7	3
Lepidoptera		1	2	0	2	0
Araneae		4	3	1	1	1
Dermaptera		0	0	0	5	0
Acarina		0	2	0	1	0
	Total	7997	4077	6529	5031	3759

January to February						
Diptera	Drosophilidae	3086	2464	2523	2255	1827
	Phoridae	29	104	136	75	70
	Sciaridae	22	9	43	10	5
	Muscidae	18	17	13	10	3
	Neriidae	8	1	2	1	0
	Syrphidae	1	1	0	3	0
	Total	3164	2596	2717	2354	1905
Coleoptera	Nitidulidae	615	651	416	636	420
	Staphylinidae	184	291	333	176	365
	Lucanidae	0	2	0	2	0
	Curculionidae	0	2	5	4	8
	Scolytidae	3	0	0	0	0
	Histeridae	0	1	1	1	0
	Total	802	947	755	819	793
Hymenoptera	Parastic wasp	93	132	55	68	85
	Honey bee	3	1	0	1	3
	Stingless bee	9	58	23	37	65
	Wasp	3	0	1	0	1
	Total	10	191	79	106	154
Hemiptera		6	8	9	3	28
Blattaria		11	14	20	16	36
Lepidoptera		1	0	0	2	7
Araneae		1	3	1	2	1
Dermaptera		0	1	1	0	0
Acarina		1	0	0	0	0
	Total	4094	3760	3582	3302	2924

April to May		1728	2943	1353	2121	481
Diptera	Drosophilidae	40	17	16	96	27
	Phoridae	3	4	4	8	4
	Sciaridae	40	20	13	24	4
	Muscidae	2	0	0	1	1
	Neriidae	1813	2984	1386	2250	517
	Total	832	279	549	598	386
Coleoptera	Nitidulidae	1587	1179	743	755	450
	Staphylinidae	2	16	2	50	1
	Lucanidae	3	2	2	3	17
	Curculionidae	16	6	3	4	11
	Elateridae	4	8	1	2	3
	Scolytidae	0	0	0	1	0
	Cerambycidae	0	0	1	0	0
	Total	2444	1488	1301	1413	868
Hymenoptera	Parastic wasp	30	16	13	32	21
	Honey bee	0	3	0	0	2
	Stingless bee	4	39	14	22	8
	Wasp	0	2	0	0	0
	Total	34	60	27	54	31
Hemiptera		3	2	4	5	0
Blattaria		2	5	5	15	3
Lepidoptera		2	3	1	1	3
Araneae		10	0	8	1	3
Acarina		1	0	0	0	0
Orthoptera		0	0	0	2	0
	Total	4309	4542	2732	3741	1425

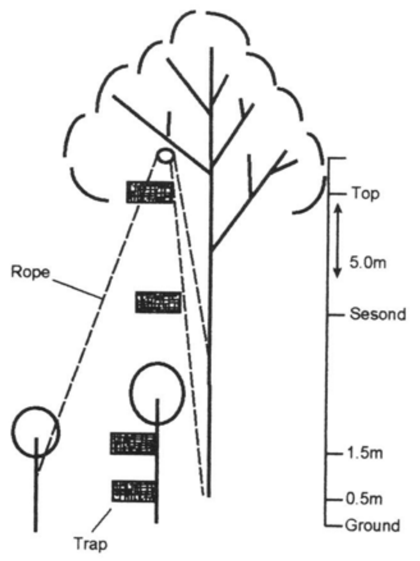

Figure 1. Trap setting by a rope-pulley system.

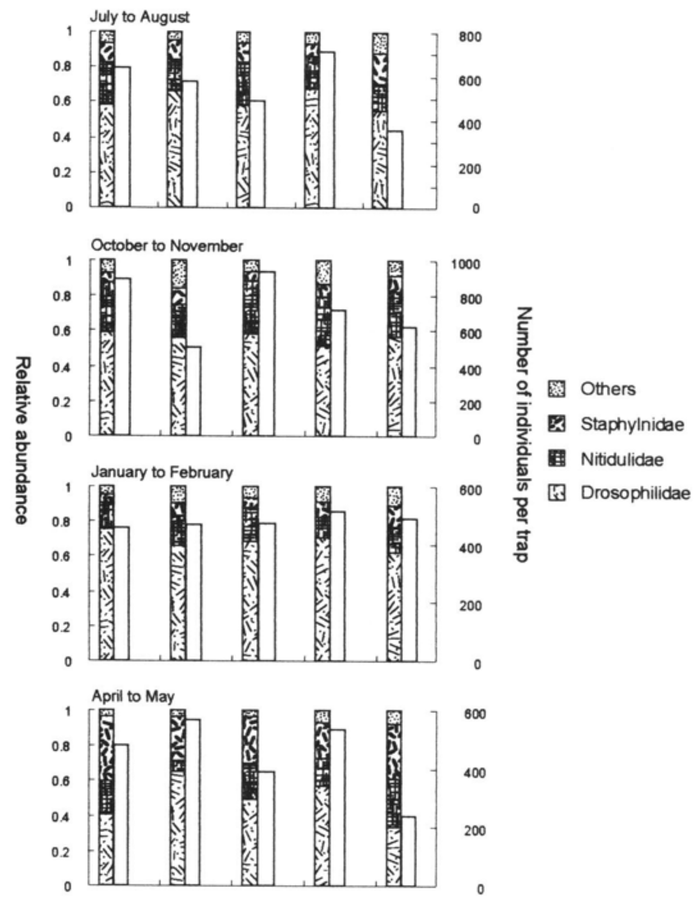

Figure 2. The relative abundance composition at the family level (left-side, shaded bar) and the number of individuals per trap (right-side, white bar) at each study plot in July to August, in October to November, 2003, in January to February and in April to May, 2004 (from top to bottom).

The impact of logging with two different minimum cutting limits on residual stand damages, beetle diversity, soil erosion, nutrient loss and water quality in the Deramakot Forest Reserve, Sabah

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Abstract An experiment was set up to assess the impact of 2 minimum diameter cutting limits: 1) 60 cm DBH for all commercial trees, and 2) 45 cm DBH for commercial non-dipterocarps and 55 cm DBH for commercial dipterocarps. Generally, the impact of the 2 treatments on the forest environment was similar. The use of RIL guidelines to carry out the logging is deduced to be the reason for this similarity. The study showed that the environmental damages associated with both cutting limits are acceptable according to the standards allowed under current RIL guidelines in Sabah. The acceptable detrimental impacts of logging on the residual trees and seedlings, beetle diversity, soil erosion, nutrient loss from the forest ecosystem in the form of logs removal and water quality in this study indicate good prospect for regeneration of the forest. Thus, strict compliance with reduced-impact logging (RIL) guidelines is effective in limiting logging damage in logged-over lowland mixed dipterocarp forest and could sustain the productivity of the tropical forest not only in producing timbers but also in providing other services such as producing clean water, as habitat for biodiversity, aesthetic values, and stabilising climate (as carbon sink).

The importance of permanent sample plots for long term observation on growth and yield and carbon sequestration: a case study in a hill mixed dipterocarp forest of Kalimantan, Indonesia

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Abstract Permanent Sample Plots (PSP) play an important role as a tool to monitor forest dynamics and changes, long term growth and yield and to provide critical data for evaluation of ecological model. For silvicultural purposes, PSP supply data on diameter and volume increment as well as stand structure dynamics. In addition to that, there has been an increasing demand for data and information collected from PSP for the accounting purposes in carbon sequestration projects under climate change agreements. Such information would support the development of the so-called baseline and additionality scenarios presented in the project development design. The use of long-term measurements provided by PSP would increase the project's profile and credibility.

In the Malinau Research Forest, East Kalimantan, 24 PSPs of 1 ha each were established in 1998 prior to logging activity and re-assessed in 2000 and 2004. Two logging systems were implemented during that period, namely reduced-impact logging (RIL) and conventional logging (CNV). A total of 705 trees species ($\geq$ 20 cm dbh) were recorded from the permanent sample plots, of which 67 (9.5%) were dipterocarp species. Among the most common Dipterocarpaceae included *Dipterocarpus lowii, D. stellatus, Shorea beccariana, S. brunescens, S. exelliptica, S. macroptera, S.maxwelliana, S. multiflora, S. parvifolia, S. rubra* and *S. venulosa*. Carbon stock in dipterocarp forest has been modeled by using CO2 Fix. It is a simple carbon bookkeeping model that consists of six modules, focusing onbiomass, soil, product, bioenergy, financial, carbon accounting.

Periodic annual diameter increment and forest regeneration were observed. Based on inventory (2000) of the regeneration plots after logging (both types), sapling density calculated from the census of the 12 plots (5 x 100 m^2 each) was more than 4600 stem ha^{-1} on average. We found that the different species of dipterocarps varied from 0.35 to 0.52 cm $year^{-1}$ according to logging intensity in RIL plots ($\geq$ 20 cm dbh), while in CNV plots, increment of dipterocarps ranged from 0.42 to 0.62 cm $year^{-1}$. A group of non-dipterocarps was also assessed. The relationship between growth (cm $year^{-1}$) and felling intensity (F_I in total number trees ha^{-1}) in the plots was also measured for dipterocarps and non-dipterocarps groups. Linear regressions are positive: $Dipt_{RIL} = 0.242\ yr^{-1} + 0.0850\ F_I$ (R^2=70.4%) and $Non\text{-}Dipt_{RIL} = 0.190 + 0.0683\ F_I$ (R^2=54.3%). The growth is less than assumed by the Indonesian Selective Cutting and Replanting System or TPTI (Tebang Pilih Tanam Indonesia) which is 1 cm $year^{-1}$. If we assume that this pattern continues, a longer cutting cycle is needed for sustainable forest management.

Keywords permanent sample plots, East Kalimantan, hill mixed dipterocarp forest, periodic annual diameter increment, reduced-impact logging, TPTI, logging damage, forest regeneration, Carbon Sequestration

Slash-*and*-char system as alternative for wood waste utilization to improve land productivity : the local perspective to manage forests sustainably

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The potential of wood waste in Malinau, East Kalimantan Current veracity in the forests of the developing countries is often at par with rich ones in terms of wastefulness. Logging concessions and shifting cultivation activities have left massive swaths of devastation, which contribute to an abundance of waste. A field study was undertaken by Center for International Forestry Research (CIFOR) in collaboration with Forestry Research & Development Agengy – Ministry of Forest (FORDA-MoF) of Indonesia and Malinau district agencies to quantify the amount of wood waste from logging and land clearance activities for shifting cultivation by local communities.

The amount of wood waste from clearance was 63 m^3ha^{-1}, while the total demand for new *ladang* was 5,000 hectares per year. Thus the total wastage produced annually is 315,000 cubic meters - enough to fill 68 football fields with rubble. In line with that, wood waste from logging was abundant, with a total of 781 m^3 for every km of new logging road and 207 m^3 for each hectare of log yard opened. With recently 5 Izin Usaha Pemanfaatan Hasil Hutan Kayu (IUPHHK) concessionaires operating in Malinau, they contributed up to 22,000 m^3 of wastage annually.

The traditional process of *ladang* opening, inherited from the ancestor, pays no special attention to its waste. The fallen trees are often left to suppress the growth of scrubs and they are burned to provide ash to the soil. The opening process only provides one planting cycle for rice or maize or mixed. Most of the ash from the burning of debris will not last long; it leaches by the following rain.

Why is it important to promote slash-*and*-char in Malinau ? Malinau is a land locked area. The district is located in the upper stream of several big rivers in North East Kalimantan. Traditional agriculture is trying to increase harvest through application of fertilizer and insecticides. The price of these chemical products, however, is too high for the farmers. The introduction of slash-*and*-char will help farmers reduce their spending if charcoal and wood vinegar are applied as substitutes of fertilizer and insecticides.

CIFOR in cooperation with Malinau Government was promoting a new system to develop slash-*and*-char activities in agriculture sector, with the intention that charcoal and wood vinegar can be widely accepted by farmers in the near future through the Agricultural Extension Officers (Penyuluh Pertanian Lapangan, PPL) of the Sub-district Agricultural services.

The benefit of slash-*and*-char for shifting cultivation Charcoal application as a soil conditioner can uphold and increase the soil Cation Exchange Capacity (CEC), soil layer effective area, soil organic-C, as well as to provide more micro- and macro-pores to control soil humidity and its water balance. Another benefit from charcoal making is wood vinegar, which is good for plant growth acceleration and to prevent micro-organisms or harmful insects on crops or vegetable fields.

Switching to slash-*and*-char from the traditional slash-*and*-burn system will increase the intensity and productivity of *ladang*, the shifting cultivation of rice and maize practiced by the local communities also would reduce the danger of forest fire - not a bad bonus in a country that has been devastated by such catastrophes in recent years. At the very least, switching to new system would reduce the demand for new *ladang* and forests opened - active participation of the local communities could support the sustainably managed forests.

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Sustainable Collaborative Forest Management
Meeting the Challenges of Decentralization in Bulungan Model Forest

Effects of lowering diameter cutting limit on understorey vegetation, litter and root biomass in tropical forest

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Abstract A study to investigate the effect of lowering diameter cutting limit from 60 cm (DCL_{60}) to 45 cm (DCL_{45}) on understorey vegetation, litter and root biomass was conducted in Deramakot forest reserve, Sandakan, Sabah. The experimental design consisted of five replicates for each treatment (DCL_{45}, DCL_{60}, and undisturbed forest as the Control). In each replicate of 30 m x 5 m (0.015 ha), there were four sub-plots each measuring 1 m x 1 m. All trees less than 5 cm diameter and 1.5 m tall were clipped from each sub-plot, oven-dried and weighted. Non-woody vegetation was also collected from these plots. Above-ground forest litters were collected from two 0.5 m x 0.5 m plots within each 1 m x 1 m plot (8 samples from each replicate). Litters were separated into fine (to a depth of 0-5 cm from surface ground), coarse (0-5 cm diameter, <50 cm in length) and necromass (>5 cm diameter). Below-ground root biomass was sampled from soil cores of 5 cm diameter to a depth of 30 cm, and separated into fine (<2mm) and coarse roots (>2 mm). The results showed that mean total understorey vegetation in DCL_{45}, DCL_{60}, and Control plots were 704 ± 168 (SE) kg ha^{-1}, 533 ± 32 kg ha^{-1}, and 526 ± 99 kg ha^{-1}, respectively, and not significantly different (F=0.778, p=0.481, N=15, ANOVA). The concentration of understorey biomass in the DCL_{45} plot was twice higher than that found in DCL_{60} and Control but comprised mainly of non-woody vegetation. Total litter biomass in the study area was much higher compared with understorey vegetation and root biomass (DCL_{45}=18,679 ± 2,405 kg ha^{-1}, DCL_{60}=18,660 ± 2,881 kg ha^{-1}, Control=16,527 ± 1,947 kg ha^{-1}). The difference in litter biomass between treatments was not significant (F=0.257, p=0.778, N=15, ANOVA) although necromass concentration had a greater influence on this outcome (p=0.049). Below-ground root biomass amounted to 7 ± 0.38 kg ha^{-1}, 9 ± 1.25 kg ha^{-1} and 11 ± 2.7 kg ha^{-1}, respectively, and was not significantly different (Chi^2=0.536, p=0.765, N=15, Kruskal-Wallis). Lowering diameter cutting limit to 45 cm had no significant effect on the total concentration of the three biomass pools in the study area. However, it changed the composition of understorey vegetation to a greater proportion of non-woody vegetation such as grass, shrubs and bamboo abundance. The silvicultural implication from this was the need to restore and carry out vine cutting operations to improve low regeneration stock. Ground litter had increased drastically as a result of the transfer of canopy biomass to ground biomass from logging. However, reducing diameter cutting limit to 45 cm did not significantly increase ground litters but this preliminary conclusion could be confounded by the accumulation of debris on the forest floor prior to logging by natural events. The apparent ease of collecting forest litter made it a potential indicator for assessing the impact of logging in primary or re-log forest. Conversely, this study had shown that lowering diameter cutting limit had reduced total below-ground root biomass associated with a higher disturbance of ground vegetation and soils. Although it is possible to draw general conclusion from this study, a complete analysis of the effect of lowering diameter cutting limit should include all trees ranging from 1 to 40 cm DBH as they alone accounted for 90% of the total biomass pool in forest. Further considerations should also include an appreciation of the biological rotation age (i.e. when mean annual increment starts to decline) of dipterocarp forest, and a valuation of the multi-benefits provided by forests.

Keywords Forest biomass, diameter cutting limits, understorey vegetation, forest litter, root biomass

Conclusion of the workshop and the scopes of the study of biodiversity and carbon in Deramakot RIL sites

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We foresee, when the Kyoto Protocol comes into effect, that the biomass stock will increase in inland and wetland ecosystems through the clean development mechanism (CDM) according to the following scenario: 1) the conversion of non-forests or less-productive open wood stand to fast-growing tree plantations, 2) the increase of agro-forestry practice, 3) the restoration of native forests and 4) the enrichment planting in recovering ecosystems. Among these scenarios, the conversion of non-forests or open forests to fast growing plantations will be implemented in the largest area in Monsoon Asia to achieve the fastest yield per unit area per unit time. This scenario is envisaged particularly in the humid tropics where land conversions took place in the last three decades.

Fast-growing plantations are typically of mono-culture with the lowest level of biodiversity of trees and accompanying fauna. These forests are in many cases of introduced exotic species. Although such forests achieve the most efficient carbon stocking at a shortest time-scale (e.g. 10 years to a few decades) for the first few rotations only, the long-term effects to the global environments can be quite damaging due to 1) the accumulated litter which will produce dissolved organic matter to soil and stream water, 2) the emission of nitrous oxides and nitrogen oxides from leguminous tree plantations, which will not reduce but exacerbate the global warming, 3) increasing the risk of forest fire by higher stocking of fuel load, 4) depleting soil minerals, and 4) the loss of biodiversity which will sustain the ecological health.

These ecological disasters can be prevented in many cases by practicing enrichment planting or restoring native forests thereby biodiversity and biological linkages are kept. For instance, the greater tree species richness may lead to faster decaying of litter, reducing dissolved-carbon loading to stream and the risk of forest fire. Due to the constraints of the current CDM rules, carbon credit is restricted to reforestation and afforestation only. The most efficient way to reconcile carbon stocking with the protection of biodiversity and ecosystem health in tropical rain forests is the truly sustainable management of production forests and the conservation of protected forests. Particularly, the role of production forests to conserve biodiversity and carbon cannot be overstated because their areas are huge and have *de facto* become the reservoir of biodiversity if logging damage is modest. In this sense, the certified production forest of Deramakot can become a pilot site where we can study and demonstrate how to manage biodiversity and carbon.

This workshop has successfully illustrated the importance of the sustainable management of the production forests with reduced impact logging in carbon sequestration and biodiversity conservation. Moreover, most speakers have demonstrated the importance of research, particularly of long-term one. We highlight the following remarks as workshop findings.

1. Reduced impact logging can be effective in increasing carbon stocking as above-ground vegetation by 70 ton carbon/ha on average in comparison to conventional logging.
2. The use of satellite data in evaluating carbon

and biodiversity at a landscape level can be an alternative to ground survey for some taxonomic groups.

3. Reduced impact logging can be effective in maintaining tree-species richness and the regeneration of dipterocarp trees.
4. Strict compliance with reduced-impact-logging guidelines can be effective in limiting logging damage in logged-over lowland mixed dipterocarp forest and in sustaining clean water and the habitat for biodiversity.
5. The natural salt licks in Deramakot can be hot spots of mammalian diversity because a cascade of food web (herbivores to carnivores) appears to be formed. Preservation of such salt licks should be incorporated into forestry planning.
6. The abundance of some insect groups at a higher-taxonomic level can be used as the bio-indicator for assessing the effects of logging especially in the understory.
7. The composition of soil fauna can be used as a bio-indicator for assessing the effects of logging.
8. Long-term monitoring of permanent sample plots can increase the profile and credibility of sustainable management of forests including biodiversity and carbon by developing the baseline and additionality scenarios.
9. The participation of local people can be incorporated in sustainable forestry though such systems as slash-and-char. This system can convert wood wastes into economically valuable goods and prevent forest clearance in the surrounding areas.